METAMORPHIC AND IGNEOUS ROCKS OF EASTERN ECUADOR

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by

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I. INTRODUCTION

The rocks, from Eastern Ecuador, described in the following pages were collected during two exceedingly difficult journeys, one in 1921(*5*)[2] and the other in 1927-1928 (*4*), in that part of eastern Ecuador called the "Oriente", lying between the Equator and 2°S Latitude, and extending from the culminating peaks of the Andes Mountains as far east as the confluence of the Napo and Coca Rivers, 77° west of Greenwich.

The geological results of the first expedition were published in part as a memoir (*7*), which was limited almost entirely to a description of the sedimentary rocks and their fossils, the latter proving the presence in eastern Ecuador of sediments as old as the Albian subdivision of the Cretaceous period.

Considerable petrographic work has been done on rocks from the Andes of Ecuador, but practically none on those from the "Oriente" or forested foothills and lowlands east of the Andes. The volcanic mountains of the lofty Andes, such as Chimborazo, Cotopaxi, etc., have been a favorite field of study for European geologists and the results of their investigations are set forth in so many papers that we cannot attempt to cite them all.

The German geologists, Wilhelm Reiss and Alphons Stübel, (*3*) may be single out for mention because of their labors, extending over a period of five years, during which all parts of the Andes of Ecuador were visited. They made collections of the different rocks encountered and submitted them to German petrographers for study. In the course of their investigations, they collected material from three localities on the western boundary of the area we are describing.

Reiss and Stübel worked in Ecuador from 1870 to 1874; in this period, they collected about 6000 specimens of igneous rocks. For the petrographic studies of these rocks over 1800 thin sections were examined by various petrographers. Even the bibliography pertaining to the work of Reiss and Stübel and their collaborators is too lengthy to be cited in this memoir.

Previous to the 1921 expedition of Sinclair and Wasson no pre-Tertiary fossils had ever been found in Ecuador. It was concluded, merely on the basis of similar rocks elsewhere, that the few outcrops of sedimentary rocks found here and there, in very disturbed conditions in the midst of igneous rocks, were of Cretaceous age. The Igneous rocks of the Andean highlands of Ecuador have, however, been described as Tertiary and Quaternary lavas, and the metamorphic rocks, consisting of schists and gneisses, are thought by all geologists who have made field studies of them, to be very ancient.

The best description of the igneous rocks nearest our area is that of Von Wolff, (*2*) who gives in great detail the results of his petrographic examination of the Reiss and Stübel collection from the peaks of the Andes along the western border of our area.

[2] Throughout the present paper italicized number enclosed in parentheses refer to references similarly designated in the bibliography.

The value of our collections from eastern Ecuador lies not only in the number of specimens and variety of igneous rocks represented, but in the fact that in this area, for the first time, the field relations between sediments of proven age, and a large series of altered volcanic rocks, were clearly seen. In the "Oriente" the Cretaceous sediments occur over wide areas in a nearly horizontal attitude and at times their lower beds may be seen underlain by certain of the igneous rocks. In the Andes it is impossible to tell whether the igneous rocks lie above or below the few sediments exposed.

The expeditions of 1921 and 1927 proved that volcanoes, hitherto thought to be limited to the high Andes, are likewise present in the foothills and lowlands far to the east. The great volcano "Sumaco" lifts its mighty cone in the midst of the Cretaceous rocks of the foothills. In 1926 a new and hitherto unknown volcano, called by the Indians "El Reventador", came into activity at a point about 30 miles east of the main Andes, and it is possible that other volcanic centers may be discovered later.

With the exception of several specimens of recent lavas collected from lava streams which have flowed down the slopes of Antisana to the Oriente, and from other localities which may represent isolated outflows of lavas, no other specimens of *recent* lavas were collected by the expeditions of 1921 and 1927, because these are so widely distributed in the Andes immediately to the west and because they have been previously described.

The only specimens of recent lavas from *eastern* Ecuador previously described in geological literature (*1*), proved to be unique in that they are the first feldspathoid lavas so far known in all of Ecuador.

II. PHYSIOGRAPHIC FEATURES

The region from which the collections were made is intermediate between the lofty summits of the Andes and the low-lying Amazon plain. On the west are the great snow and glacier-capped peaks of Cayambe (19000 feet), Antisana (18700 feet), Cotopaxi (19300 feet), Tungurahua (16500 feet), El Altar (17400 feet) and Sangay (17100 feet). On the east, at the confluence of the Napo and Coca Rivers, and only ninety miles from the above line of summits, elevations as low as 850 feet above the sea are found. This general slope is interrupted by minor mountain masses, themselves of great elevation and prominence. The gigantic volcanic cone of Sumaco, for example, rears itself to an elevation of 12500 feet half-way between Antisana and the confluence of the Napo and Coca Rivers. The still unexplored Galeras Mountains, twenty-eight miles south of Sumaco, have summits about 5400 feet above sea level and the volcano "El Reventador", recently become active and situated about forty-five miles north of Sumaco, is a prominent mass about 6000 feet above sea level. Thus, the area is one of strong topographic features.

The rivers descend from the snow-covered summits of the Equator in profound gorges, leaping in places down great cataracts and reaching the "fall line", in almost continuous rapids, at about 850 feet elevation.

III. DIFFICULTIES OF EXPLORATION

The difficulties of exploring this region are made almost insurmountable by the excessive rainfall which, in places, attains seventeen feet per annum, and by forests which cover the entire area up to an elevation of about 10000 feet above the sea. In these forests the few footpaths are but gloomy tunnels through the vegetation, where the traveler wallows knee-deep in mud and is subjected to a constant downpour from rain and from the dripping trees. The temperature and climatic conditions vary from the tropical heat prevalent at the mouth of the Coca to the snow storms of the high passes, which have an elevation of 13000 feet. The population is exceedingly limited. Dwellings of Indians are found at very rare intervals and the occasional widely separated villages of the white pioneers have very few inhabitants.

IV. PETROGRAPHY

The forty-four samples of rocks described in the following pages, collected east of the Andes during the two expeditions of 1921 and 1927, may be divided into five groups:

A. Metamorphic rocks: schists of various types.
B. Igneous rocks: chiefly surface types, of proven pre-Albian age.
C. Igneous rocks: chiefly surface types, probably also pre-Albian, but whose age is not certain because their outcrops are distant from occurrences of sediments of known geologic horizon.
D. Granites.
E. Lavas of late Tertiary, Quaternary and Recent age.

The name of each rock and the group to which it belongs on the basis of the above classification are shown in Table I.

The igneous rocks, excepting the granites and schists, might be subdivided into two sub-groups, (1) surface flows and tuffs, of unquestioned pre-Tertiary age because of the profoundly altered condition of the rocks; and (2) volcanic rocks of Tertiary to Recent age, because of the lack of alteration of any of the primary minerals.

A. METAMORPHIC ROCKS

The Schists

The “core” of the Andes of Ecuador consists of metamorphic rocks, schists and gneisses, of unknown age, although they are generally considered pre-Paleozoic and are judged to be a part of the wide-spread formation of the same character common in many parts of South America.

In Ecuador these schists and gneisses outcrop from the Peruvian to the Colombian borders in an almost continuous, narrow band, running nearly north and south like the main Andean cordillera. The line of lofty volcanic peaks forming the Eastern boundary of the high Andes and the eastern slopes of these mountains down to what may be called the base of the Andes are included in this area.

The schists are exposed at elevations as high as 13448 feet[3] above the sea in this belt in Ecuador. In the western part of the Andes, they are generally concealed beneath enormous masses of lavas and tuffs, the products of Tertiary and recent volcanic action. It is fairly logical to conclude that these schists are the oldest rocks of Ecuador. The peculiar narrowness of their outcrop suggests that they form the exposed base and sides of a great fault-block which is tilted westward toward the Pacific Ocean.

The schists described in this memoir were collected from the Papallacta gorge, one of the great gorges which cut into the eastern slope of the Andes, in which waters of the Río Papallacta and the Río Quijos unite to form the Río Coca. They were first encountered at an elevation of 9400 feet; proceeding eastward down the gorge they disappear at an elevation of 6400 feet. They thus outcrop in a vertical range of 3000 feet. The width of this belt in the Papallacta gorge is about fourteen miles. At the upper boundary in the vicinity of the village of Papallacta they vanish beneath late Tertiary lavas and tuffs and do not reappear anywhere in the thirty-three miles between this point and Quito, although during the traverse we ascended to over 13000 feet above the sea and descended as low as 7400 feet.

The nine samples collected in the above-named gorge are intensely metamorphosed rocks. They are all crystalline schists, folded, crumpled, and presenting all the aspects of rock that has been subjected to regional dynamic metamorphism in conjunction with attack from a subjacent igneous source. They present an exceedingly complex history involving an origin that in some cases was certainly igneous, in others probably sedimentary.

Since there are some interesting features connected with the samples, they are here described in detail. Furthermore, with the exception of the three samples collected by Reiss and Stübel in August 1871[4], no description has been published of these Papallacta Valley schists.

- ***Specimen No. 1*** was collected from a massive outcrop 2.5 miles east of the hamlet of Papallacta, on the left bank on the river along the trail at an elevation of 9404 feet.

It is a light gray rock with variable texture, carrying much glistening scaly sericite; it is very streaked and heterogenous in make-up, coarse, foliated and strongly sheared, with the general aspect of a schist.

Petrographically the rock proves to have been initially igneous in origin: either a granite or granodiorite. The original character is considerably obscured by shearing and by reason of the changes brought about through the modification of the former components by the attack of igneous matters. There is, therefore, an antecedent structure within the rock, inherited from a former condition, and in addition secondary structures imposed upon it as well. The original minerals consisted largely of hypidiomorphic plagioclase feldspars, biotite, and perhaps quartz, although it is uncertain how much of the quartz was present initially as primary orthotectic quartz and how much invaded the rock during the later metamorphic stage

[3] Feldspar-rich mica schists somewhat phyllitic, from the west summit of Jacatuna de Numuloma western foothills of Antisana, according to Reiss and Stübel.

[4] The collection of Reiss and Stübel consists of a "phyllite gneiss" from the church at the village of Papallacta, boulders of phyllite gneiss in the Río Papallacta at the mouth of the Yurac-yacu and a "muscovite mica schist" carrying abundant carbonaceous matter from the Papallacta valley between the hamlet of Papallacta and the mouth of Yurac-yacu.

TABLE I

		Locality	Sample No.	Name of Rock
METAMORPHIC	**SCHISTS**	Río Papallacta	1	Orthoschist of complex origin
		Río Papallacta	2a	Orthoschist of complex origin
		Río Papallacta	1a	Quartz sericite schist
		Río Papallacta	3	Sheared rock; mylonitized
		Río Papallacta	4	Helicitic mica schist
		Río Papallacta	5	Sismondite schist
		Río Papallacta	5a	Sheared meta-diorite porphyry
		Río Papallacta	6	Sheared meta-diorite porphyry
		Río Papallacta	6a	Sheared meta-diorite porphyry
		Río Papallacta	7	Orthoschist (Greenstone schist)
		Río Quijos	8	Biotitic schist of complex origin
		Río Quijos	9	Schistose rock of complex origin
IGNEOUS	**(a) PRE-ALBIAN (PRE-MIDDLE CRETACEOUS) VOLCANICS**	Río Coca	1L	Devitrified acid volcanic tuff
		Río Coca	L-a	Devitrified volcanic ash
		Río Coca	Z	Meta-andesite
		Río Coca	1	Trachy-andesite or latite
		Río Coca	1-a	Latite tuff or tuffaceous latite
		Río Coca	2	Acid volcanic tuff
		Río Coca	3	Spherulitic felsite
		Río Coca	4	Volcanic tuff
		Río Coca	5	Modified basalt
		Río Coca	6	Andesitic tuff
		Río Coca	17	Basaltic andesite
		Río Coca	18	Porphyritic latite
		Río Misahuallí	A	Tuffaceous trachytic felsophyre or modified trachytic ash
		Río Misahuallí	69	Trachytic felsophyre
		Río Misahuallí	71	Altered basaltic amygdaloid
		Río Misahuallí	72	Altered basalt
		Río Misahuallí	72-c	Altered amygdaloidal basalt
		Río Misahuallí	73	Dellenitic tuff
		Río Jandache	B	Dellenitic vitrophyre
	(b) PROBABLE PRE-ALBIAN VOLCANICS. Excepting Nos. 11 and 12.	Río Pastaza	7a	Rhyolite
		Río Pastaza	7c	Rhyolite
		Guacamayos Mt.	A	Weathered monzonite porphyry
		Guacamayos Mt.	B	Spherulitic granophyre
		Guacamayos Mt.	C	Gabbro, much altered
		Río Papallacta	2b	Silicified, kaolinized andesite. Included here for convenience
		Río Quijos	12	Serpentinized rock
		Río Quijos	11	Limestone breccia
	(c) GRANITES	Río Urcusikiyacu	a	Biotite granite
		Río Napo	b	Biotite granite
		Río Pastaza	7b	Graphic granite
	(d) QUATERNARY LAVAS	Río Papallacta	10	Basalt
		Río Cosanga	2	Andesite

The plagioclase is fracture and microfaulted; the older plagioclase is almost wholly, if not entirely, replaced and modified so that only the "ghosts" of it remain. The modification products consist of little prisms of zoisite, grains of epidote, shreds of sericite, little grains of garnet, some of them quite idiomorphic, and turbid patches composed of a very minutely granular aggregates of the same set of products just mentioned, that correspond to saussurite. All of these products are confined within the limits of what was the original plagioclase; they are now included in new crystals of albite that extend beyond the limits of the older plagioclase and which have largely replaced the older feldspar. In places the albitized plagioclase has taken on a "pseudo-perthitic" structure due to deformation, subsequent to the period of replacement, that ruptured and displaced the albite twinning so that the feldspar, at first glance, resembles microperthite. Only the merest traces of the structure and the substance of the earlier plagioclase are preserved, but the *forms* of the older plagioclase are in places emphasized by the groups of alteration products just referred to.

The biotite seldom retains any semblance of its original form; it is commonly squeezed out into streaks composed of fine shreds and minute flakes of colorless mica mixed with yellowish-white opaque specks of leucoxene, specks of iron-oxide and grains of quartz. There are a few remnants that still retain some suggestion of their original shapes, but even these are bent and distorted, and all of them are altered in the manner described.

FIG. 1 – *Papallacta No. 1* – Orthoschist of complex origin. Drawing, ordinary light, showing relics of older feldspar in later albite. The older feldspar consists of aggregates of zoisite-epidote-sericite, garnet grains, and minutely granular aggregates of the same set of products. Colorless areas are quartz with inclusion trains. ×43

The later albite is filled with both crystal and bubble and liquid inclusions, roughly oriented, and commonly intersecting the cleavage directions at an oblique angle.

Quartz, albite and a little muscovite were introduced into the rock during the later stages of its metamorphism, transecting fractured feldspars and distributed in streaks and patches. Even the later quartz and albite that were introduced and whose feldspar has in part replaced the older feldspar of the rock, have been deformed by fracturing and granulation, so that at least two stages of deformation are recorded; one was connected with the period of "soaking" by granites juices that effected replacement of earlier feldspars and the "granitization" of the rock; the other, and later, post-granitization period of deformation granulated and fractured both the granitized rock and the replacement matter. In addition, there is evidence that the introduction of quartz continued subsequent to the later deformation, since in both No. 1 and No. 2a there are areas of quartz and associated calcite in granular mosaic aggregates that exhibit no signs of deformation at all.

- ***Specimen No. 2a***, taken 6.7 miles east of Papallacta at an elevation of 8571 feet, is similar to No.1 in character, structure and history. This is a light colored, streaked and schistose, coarse textured rock. The plagioclase is fractured and crowded with innumerable inclusions consisting largely of coarse sericite, with less epidote and zoisite, garnet grains, granular titanite and chlorite. The same set of products mixed with granular quartz, albite and a little pyrrhotite, are distributed along fracture zones as well. There is considerably more calcite associated with the introduced quartz and feldspar than in Specimen No.1, but the two specimens are very much alike in other respects.

Despite the fact that these two specimens were secured from exposures four miles apart and differing in elevation eight hundred feet, they are essentially alike in composition, and the sequence of events recorded in them is the same.

Some of the features described are shown in Figure 1, which is a drawing from a thin section of Specimen No.1, and in Figure 2, a photomicrograph of Specimen No.1, taken with nicols crossed. The drawing, which represents the appearance of the section in ordinary light, shows the older plagioclase crowded with very fine, dense aggregates of epidote-zoisite, mixed with larger grains and prisms of the same minerals, in an albite matrix that extends in clear areas beyond the original margins of the older plagioclase.

The photomicrograph (Fig. 2), taken at a lower magnification than the drawing (Fig. 1), illustrates the same set of conditions. Although there is little suggestion of schistosity in either the drawing or in the photomicrograph the rock itself is not only coarsely foliated but exhibits injection effects as well. It is clearly an orthoschist, but it has an added complexity due to soaking, injection and resultant modification and replacement brought about either by an attack of the end-stage concentration-residua of the same magma that gave birth to the granodiorite or to an attack by a later magma.

FIG. 2 – *Papallacta No. 1* – Photomicrograph of the same schist shown in Figure 1, nicols crossed. Note the relic structures of older feldspar in later albite, and the granular aggregate of zoisite-epidote-sericite in the fresh albite. ×34.

***Comment on Analysis**:* An analysis of the rock, compared with averaged analyses of 10 granodiorites, 20 quartz-diorites, and a combined average of 37 analyses of tonalite, quartz-monzonite and granodiorite, shows marked differences in the proportions of certain of the constituents, more especially when the analysis of Papallacta No. 1 is compared with the average for granodiorite.

The average granodiorites (Nos. 2 and 4, Table of Analyses) carry three times as much potash as sample No.1 from the Papallacta trail, but only two-thirds as much soda. The lime is higher in the average granodiorites, but the magnesia is considerably lower. The percentages of silica and alumina, however, in the averaged analyses of granodiorites, are nearly equal to the silica and alumina in sample No.1, Papallacta. The analysis of the Papallacta rock is not at all comparable with the average of twenty analyses of quartz-diorites, which is included here merely for the purpose of extending the range of comparison. These differences in the composition of the Papallacta rock, compared with the composition of average granodiorite, may be due in part to the entrance of igneous emanations from a subjacent source, and the replacement of feldspar, originally richer in potash, by soda-rich emanations. While the rock, judging merely from the thin section, is a sheared and modified granodiorite, it is probable that this particular specimen happened to contain more of the granodiorite material than of the older schist invaded by the granodiorite, so that there are but traces of the older schist in this sample.

TABLE II: TABLE OF ANALYSES

		1	2	3	4	5	6	7|	8	9
Silica	SiO_2	67.54	67.18	59.47	66.10	65.30	60.42	60.50	56.76	63.40
Alumina	Al_2O_3	15.26	15.45	16.52	15.32	18.02	16.32	18.20	16.20	16.57
Ferric Oxide	Fe_2O_3	1.29	1.75	2.63	1.97	1.17	1.93	4.52	4.16	1.90
Ferrous Oxide	FeO	2.82	2.27	4.11	2.90	4.71	2.62	0.86	3.36	1.90
Magnesia	MgO	2.85	1.55	3.75	1.77	2.87	3.82	2.87	4.08	2.14
Lime	CaO	2.16	3.57	6.24	3.81	0.98	5.06	2.39	5.82	3.83
Soda	Na_2O	4.94	3.63	2.98	3.48	1.12	4.41	4.63	3.93	4.77
Potassa	K_2O	0.92	2.79	1.93	2.74	2.47	0.65	1.90	2.39	3.48
Water 110°	H_2O -	0.04	-	1.39	1.06	0.00	0.01	0.59	-	-
Water over 110°	H_2O +	0.81	-	-	-	1.93	0.90	1.96	-	-
Titanium Oxide	TiO_2	0.68	0.50	0.64	0.53	0.50	0.58	0.74	0.96	0.48
Phos-Pentaoxide	P_2O_5	0.10	0.23	0.26	0.27	0.10	0.10	0.10	0.25	0.21
Manganous Oxide	MnO	0.28	0.21	0.08	0.04	0.39	0.47	0.80	0.12	0.07
Sulphur tri-oxide	SO_3	0.07	-	-	-	0.03	0.09	0.09	-	-
Carbon dioxide	CO_2	0.04	-	-	-	0.29	1.72	0.03	-	-
						Iron (as Fe) Sulphur as S)	0.37 0.21			
TOTAL		**99.8**	**99.13**	**100.00**	**99.99**	**99.88**	**99.68**	**100.18**	**98.03**	**98.75**

1. Sample No. 1. Papallacta. Analysis by Ledoux & Co., New York
2. Average of 10 analyses of granodiorites
3. Average of 20 analyses of quartz-diorites. Daly, R. A., Igneous Rocks and Their Origin [Las Rocas Ígneas y su Origen], 1914, p. 26.
4. Average of 37 analyses of tonalite, quartz monzonite, granodiorite. Daly, R. A., *Idem,* p. 25.
5. Sample No. 5, Papallacta. Analysis by Ledoux & Co., New York
6. Sample No. 6, Papallacta. Analysis by Ledoux & Co., New York. *Note:* This sample contains pyrite and traces of galena.
7. Sample No.6, Río Coca. Analysis by Ledoux & Co., New York
8. Average of 12 analyses of andesites. Bul. 419, U.S.G.S., 1910.
9. Average of 6 analyses of diorite porphyry. Bul. 419, U.S.G.S., 1910.

- ***Specimen No. 1a***, 2.5 miles east of Papallacta, elevation 9404 feet, is a moderately fine textured *quartz-sericite schist* of uncertain initial origin. Although the sample was secured in the same place as No.1, there is but little resemblance between them except in the matter of certain minerals that are common to both. The rock consists of quartz, prisms of zoisite and epidote, streaks and plates of chlorite and muscovite, a little blue-green amphibole, clear untwinned feldspar of lower index than balsam (< 1.535 ±) and with extinction angles measured from cleavages that range from 10° to 30°, a most unusual feature; granular titanite, crystals of zircon and a little pyrrhotite, all oriented in the plane of schistosity of the rock. The streaks and plates of muscovite and chlorite, the little prisms of epidote, zoisite and blue-green amphibole and some of the quartz that is elongated in the plane of schistosity, are responsible for the schistose structure. But there are streaks of quartz and feldspar that are quite granular and mosaic-like and which impart no schistosity to the rock at all. These have the character of injected matter derived from an igneous source; that is, these streaks are judged to be *lit-par-lit* injections of a sort.

There is no direct evidence bearing on the initial condition of the rock; it is impossible to determine whether it represents an intensely metamorphosed sediment or whether it is a strongly sheared and highly metamorphosed portion of the granodiorite, although it seems more probable that this sample represents the older schist, of sedimentary origin, rather than an intensely sheared phase of a massive rock like the granodiorite. Whatever the original condition, the rock has not only been converted into a crystalline schist, but it has also been affected by injections of matter under igneous control, a circumstance favoring the conclusion that this specimen represents some of the older schists of probable initial sedimentary origin.

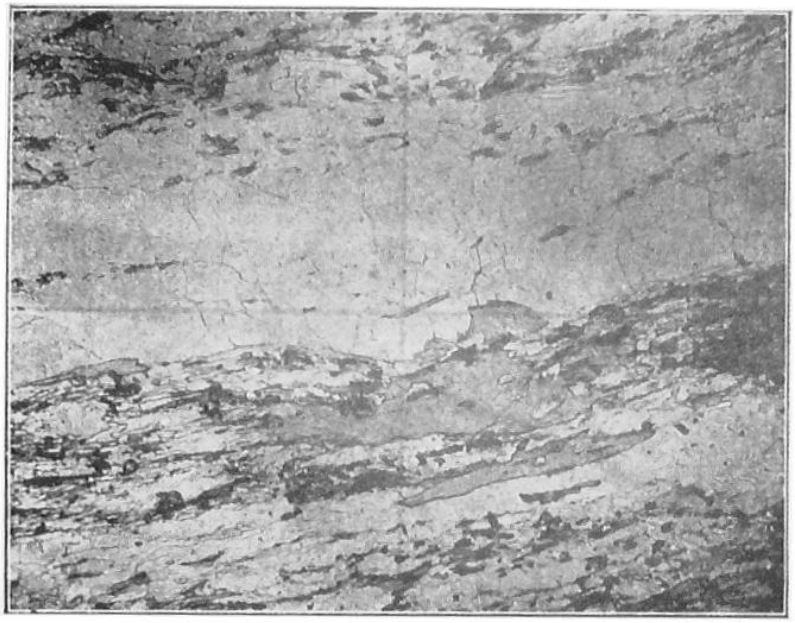

FIG. 3 – *Papallacta 1a* – Quartz sericite schist. Photomicrograph, ordinary light, showing schistosity. The band in the upper half of the picture is a granular mosaic of aggregate quartz with undeformed grains. The large darker gray patches are chlorite, the small grains and prisms are epidote and zoisite, the lighter colored foils and needles are sericite. ×24.

The character of this rock is shown in Figure 3, which illustrates some of the conditions described and which presents a striking contrast to Specimen No.1, Figures 1 and 2, although both samples came from the same locality.

- ***Specimen No. 3***, 7.5 miles east of Papallacta, elevation 8330 feet, is a coarse textured, brown, iron-stained, chalky-spotted, sheared rock resembling a sheared and weathered granite or granodiorite. It has been subjected to crushing of considerable intensity, so that the rock is more or less mylonitized, and much limonitic matter has developed, together with a white, opaque substance distributed in streaks that cut all the other minerals in the rock. There are uncrushed patches and streaks of coarsely granular, interlocking mosaic-aggregates of quartz, areas composed of very fine, brilliantly polarizing, flaky aggregates of colorless mica, and coarser muscovite, in aggregate groups, that is associated with alkali feldspar and that carries innumerable inclusions oriented transverse to the cleavage of the mica; under high magnification these prove to be long and narrow cavities filled with liquid and bubbles.

There is evidence indicating two stages of deformation; the earlier was the more intense. It is judged that during this stage the rock was crushed and granulated. The other and later period was productive of fractures that cut all of the other structures in the rock. Surface agencies have attacked the rock along these later weaknesses with the production of limonitic matters.

While the initial character of the rock is very obscure, it is probably an extensively sheared phase of the granodiorite.

- ***Specimen No. 4***, 9 miles east of Papallacta, elevation 8114 feet, is strongly schistose, folded and crumpled, black and white laminated, and very micaceous. It has all the aspects of a soaked, injected, silvery mica schist.

FIG. 4 – *Papallacta* No. 4 – Helicitic mica schist. Drawing, ordinary light, showing helicitic structure. The relic schist structure, now preserved in the form of carbonaceous dots and streaks, passes through the later replacing quartz and feldspar, which of itself is not schistose at all. ×24.2.

In thin section it exhibits an extremely striking helicitic structure, by reason of the replacement of the body of the schist with granular quartz and an optically positive feldspar that is occasionally twinned after the Carlsbad law, whose indices of refraction are lower than the index of the balsam, and with extinction angles as high as 25° measured from well-developed cleavage; a feature similar to that mentioned as occurring in Specimen No. 1a.

The crystals of feldspar are allotriomorphic to hypidiomorphic, very rarely exhibiting albite twinning. They are metapoikilitic carrying many inclusions consisting of minute blebs of quartz, many small prisms of zoisite, grains of zircon, little tourmaline crystals, epidote grains, titanite grains, prisms of apatite, and considerable fine, black and possibly carbonaceous or graphitic matter, all distributed in a crumpled, schistose structure that passes indifferently through the grains and the boundaries of the grains of the replacing quartz and feldspar, as well as through crystals of muscovite that is associated with the quartz and feldspar. These “ghosts” of schistosity serve to emphasize the relic structure in the schist.

There are also bands of clear aggregate quartz, likewise mixed with feldspar and with a very faintly green, beautifully twinned clinochlore.

The specimen shows more or less clearly:

(a) The development of a schist from an unknown, but probably sedimentary, original, by metamorphic processes of considerable intensity. The schist may have been initially a phyllite derived from a sediment, somewhat crumpled, and perhaps somewhat graphitic.

(b) Soaking, injection and actual replacement by end-stage concentration residua from a granitic or granodioritic source; much of the quartz and all of the feldspar belong to this stage and it is probable that the clinochlore and muscovite are products formed by the action of the emanation-residua on the matter composing the original schist.

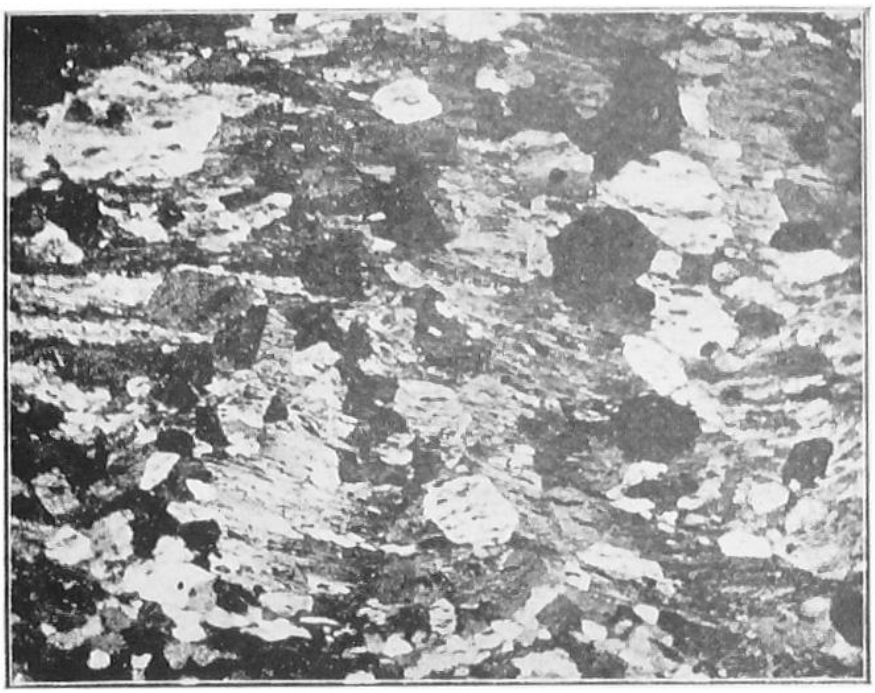

FIG. 5 – *Papallacta* No. 4 – Photomicrograph of the same schist shown in Figure 4, nicols crossed. Note the granular aggregates of undeformed quartz and albite, replacing the substance of the rock, and containing ghost structures of the original phyllite. ×24.

This very striking rock, with its beautiful helicitic structure and clearly indicated history of the replacement of an original phyllite by emanations from a magmatic source, is illustrated by Figure 4, drawing made in ordinary light, showing the relic structure of the schist passing indifferently through the replacement-mosaic of quartz and feldspar; and by Figure 5, a photomicrograph taken at a lower magnification than that represented by the drawing, showing the aspect of the section between crossed nicols.

FIG. 6 – *Papallacta No.5* – Sismondite schist. Drawing, ordinary light, showing rosettes, grains and prismoids of ottrelite (sismondite). The colorless portions are quartz. Schistosity due to arrangements of sismondite also shown. ×43.

- ***Specimen No. 5***, 10.1 miles east of Papallacta, elevation 7579 feet, is a fine texture, silvery gray, *muscovitic schist*, composed of quartz elongated in the plane of schistosity, long sinuous streaks of muscovite that at times enclose microscopic augen composed of compound grains of quartz, and prisms, bundles, groups and rosettes of a colorless variety of chloritoid corresponding to sismondite. The rosettes are formed of prismoids radiating from centers that consist of unit and compound quartz grains filled with minute included grains of sismondite. The prisms exhibit polysynthetic twinning, a common characteristic of ottrelite; the lack of both color and pleochroism suggests, however, that the crystals carry more magnesia and much less iron than ordinary ottrelite. The analysis of the rock supports this statement; most of the magnesia reported in the analysis is probably contained in the sismondite, since the only other essential components in the rock are muscovite and quartz. There are minutely microscopic crystals of rutile sparsely disseminated in the rock, many exhibiting geniculate twinning on a microscopic scale. Provided the greater part of the magnesia is contained in the sismondite, the rock should carry almost 15% of that component. This corresponds approximately with the mineral composition exhibited by the section.

Comment of Analysis*:* The alumina (18.02%) is higher in proportion to the silica (65.03%) than is normal for a rock carrying the amount of combined alkalies ($K_2O + Na_2O = 3.59\%$) that this one does, and the lime (0.98%) is relatively low (see Table of Analyses), assuming the schist to have been derived from an igneous rock. The potash and soda are probably contained for the most part in the muscovite, although some of the soda may be in the sismondite. The iron is probably distributed in large part in both the muscovite and sismondite.

FIG. 7 – *Papallacta No. 5* – Photomicrograph of the same schist shown in Figure 6, ordinary light. Rough, high relief prisms and grains are sismondite. The lower relief streaks are muscovite, the plain, smooth areas are quartz. ×33.

From the chemical composition and mineralogical make-up of the rock, it is judged that this quartz-muscovite-sismondite schist was derived by intense dynamic metamorphism from a former sediment, rather than from an igneous rock.

The character of the rock is illustrated by Figure 6, drawn from the thin section in ordinary light, and by Figure 7, a photomicrograph taken in ordinary light. Some of the prismoids and rosettes of sismondite, the muscovite and quartz, and the general schistose habit of the rock, are shown.

- ***Specimens Nos. 5a, 6* and *6a*** are much alike. No. 5a was secured in the same locality as the sismondite schist No. 5, just described, 10 miles east of Papallacta. Nos 6 and 6a came from a locality 10.7 miles east of Papallacta, at an elevation of 7561 feet.

All of these rocks are intensely sheared and thoroughly metamorphosed porphyries that were probably initially dioritic in composition. In No. 5a the original phenocrysts of plagioclase feldspars now consist of finely granular aggregates of zoisite, epidote and albite, a little calcite and occasionally a little quartz and chlorite. Much finely granular epidote is also distributed through the groundmass, which has been entirely recrystallized into a crudely oriented, interlocking, crystalline aggregate of granular quartz, albite, garnet grains, calcite, and shreds, streaks, patches and corroded crystals of biotite. Many of the albitized phenocrysts show partial replacement by epidote and zoisite and more or less granulation along their margins; in a few instances they have been subjected to much more extensive granulation. These rocks are intensely sheared, epidotized, albitized (saussuritized), modified and reorganized metadiorite porphyries.

The groundmass of Samples No. 6 and 6a is a recrystallization and modification complex of quartz, albite, epidote, calcite, muscovite, clinochlore, and a little pyrite and pyrrhotite.

The saussurite pseudomorphs after the plagioclase phenocrysts act as augen of a sort, since the groundmass minerals swing around them in lines of dynamic flowage. In Nos. 6 and 6a the same set of conditions prevails but most of the original feldspar phenocrysts are albitized and not so thoroughly saussuritized as those in Specimen No. 5a. others have been partly, and some wholly, converted into coarsely crystalline aggregates of epidote. Corroded brown hornblende crystals are sparingly distributed in the groundmass, as well as ragged patches and streaks of clinochlore.

FIG. 8 – *Papallacta No. 5a* – Sheared and modified metadiorite porphyry. Photomicrograph, ordinary light. The black crystals are pseudomorphs of finely granular saussurite (extremely finely granular aggregates of zoisite-epidote-albite) after feldspar phenocrysts. The groundmass is composed of granular quartz and feldspar and little biotite crystals which are filled with minute bubble inclusions. ×24.

Some of the features mentioned are shown in Figure 8, a photomicrograph of Sample No. 5a, taken in ordinary light. The black patches are minutely granular saussuritic aggregates pseudomorphs after original plagioclase phenocrysts. The completely recrystallized and modified groundmass consists largely of quartz, albite, and biotite. The innumerable minute dots in the quartz and albite of the groundmass are bubble and liquid inclusions.

Comment on Analysis*:* An analysis of Sample No.6 is given in the table of analyses, and for comparison the average of six analyses of diorite porphyry is likewise included.

The silica in Papallacta No.6 is lower than the average of the diorite porphyries, but all the other constituents with the exception of potash and manganous oxide are in reasonable agreement, although both magnesia and lime are higher in the Papallacta rock. There is less than one-fifth as much potash and almost seven times as much manganous oxide in Papallacta No. 6 as shown by the averaged analyses of diorite porphyry. Among the superior analyses of igneous rocks listed by Washington (*6*), in only two of twenty-three analysis of diorite porphyry cited is the potash less than one per cent., and in but one analysis is less than three per cent. of soda reported.

The average potash content of the twenty-three analysis is 2.52%, the average soda content 4.14%, figures comparable with the averaged alkali content of the six diorite porphyries listed in the table of analyses.

Excepting the low potash content, the composition of Sample No.6 Papallacta is comparable with the compositions of diorite porphyries the world over, so that the shearing and metamorphism of the rock may have resulted in the development of schistosity and in recrystallization of the primary substances without the addition of any other constituent and without the subtraction of any material from the rock, unless some of the potash originally present was eliminated during metamorphism, and a little soda, and perhaps water, added.

- ***Sample No. 7***, 12.5 miles east of Papallacta, elevation of 6972 feet, is quite different from the preceding specimens. It is a fine, schistose, indurated green rock. The color of the rock is due to abundant, emerald green, strongly pleochroic plates of lamellar clinochlore, oriented in the plane of schistosity. Both epidote and zoisite in grains, prisms and aggregate masses are likewise abundant, and the rock contains much granular quartz and alkali feldspar, some in the form of albite, some as allotriomorphic, untwinned grains. Quartz, feldspar, clinochlore, epidote and zoisite make up nearly the whole of the rock. There is a little colorless mica occasionally intergrown with the clinochlore, and there are bands of mosaic quartz, parallel to the schistose structure of the rock, that have the aspect of later, or injection, quartz. The initial character of the rock is very obscure, but the composition of it, as observed, in thin section, suggests derivation from an igneous rock of medium basic character, perhaps somewhat similar to the sheared, albitized and metamorphosed diorite porphyries Nos. 5a, 6 and 6a, although the large amount of chlorite and epidote, and the lack of remnants of former phenocrysts, as well as the finer texture, suggest derivation from an igneous rock such as andesite or basalt. It is essentially a greenstone schist in its present condition.

- ***Specimen No.8***, 14.4 miles east of Papallacta, elevation 6600 feet, is a moderately fine textured, greenish-gray, strongly biotitic schistose rock. The schistose structure is caused by shearing and recrystallization. The biotite, but crudely oriented, is distributed in long streaks and in ragged scales, flakes and patches. It is light brownish-green in the position of maximum absorption, and almost colorless in the position of least absorption. Many of the biotite flakes carry included grains of epidote and an occasional one exhibits deep brown pleochroic haloes around minute included crystals of some sort, perhaps microscopic zircon crystals. There is a little pale green clinochlore with characteristic polysynthetic twinning, and much almost-colorless epidote and associated zoisite, in swarms of grains, in larger prismatic crystals and in groups of grains. These are very prominent minerals in the rock. There is also considerable mosaic-like quartz and a pseudoperthite similar to that mentioned as present in Specimen No. 1, consisting of former plagioclase that was albitized and sufficiently deformed during subsequent shearing of the rock to have developed interrupted and offset albite twinning that resembles at first glance a microperthitic structure. Very much less prominent accessory minerals are muscovite, random small crystals of garnet, granular titanite, and a little pyrite in sharply euhedral and undeformed crystals.

Some of the quartz is distributed in mosaic-like grains that exhibit no crush-structures whatever, acting as hosts for assemblages of epidote-zoisite grains; but there are other places in the section where both quartz and feldspar have been granulated. While the original character of the rock is obscure, the composition and mineral assemblage suggest that it may have been derived from the same granodiorite that was the source of Specimen No.1. It is a biotitic schist of uncertain origin.

- ***Specimen No. 9***, 16 miles east of Papallacta, elevation 6375 feet, is a fine, streaked, silvery gray schistose rock. Local areas within the section are schistose, but there is no constancy of orientation of the grains. There are, however, shear structures of later origin that cut all the other structures in the rock, and along these weaknesses a little muscovite, prisms of zoisite, epidote, and considerable carbonate, pyrite and pyrrhotite are distributed. The sulphides must have been introduced, however, subsequent to the periods of deformation, since they cut and in part replace other minerals in the rock; they are distributed interstitially in irregular stringers, they cut through quartz, feldspar and carbonate indifferently, and they transect prisms of zoisite and epidote and fill the transverse fractures in them. The same situation prevails, in part at least, with respect to the magnetite. The calcite also encroaches on other mineral grains, although the sulphides, as previously stated, are distinctly later than it, according to the structural relations between the two minerals.

Quartz and albite are prominent minerals in the rock, both full of minute inclusions in the form of opaque (magnetite?) and transparent grains, and short, stout, but extremely minute crystals and long transparent “needles”. The feldspar is albite, nearly all of which has suffered deformation; much of it exhibits interrupted and off-set twinning and carries swarms and trains of liquid and bubble inclusions in addition to those already enumerated. Most of the “needles” resemble long, thin cavities rather than crystals. They are interrupted by cross fractures, they are irregular in width, they are terminated by rounded ends and many of them contain minute inclusions themselves which may, perhaps, be excessively small bubbles. The rock is probably a sheared portion of the granodiorite.

B. IGNEOUS ROCKS

a. Pre-Albian Volcanics

In three localities in eastern Ecuador, on the Río Coca, the Río Misahuallí and the Río Jandache, the sedimentary rocks which are only slightly inclined, are underlain by greatly altered volcanics, most of them modified tuffs. The remarkable similarity of these igneous rocks from widely separated localities, and their similar relation to the same sediments, lead us to believe that these igneous rocks are of the same age.

Fossiliferous limestones of Albian (Middle Cretaceous) age are separated from contact with these igneous rocks by only a few feet of sediments; in one place they are sandstones, in another, similar limestones. It is possible that among these beds beneath the Albian marine limestones are representatives of all or some of the Ordovician, Devonian, Carboniferous, Jurassic and Lower Cretaceous sediments that are found in Perú only a few miles to the south.

It is certain that these igneous rocks are of Pre-Albian age. It is probable that they are very much older, because they seem to be surface accumulations of lava and tuffs and not intruded igneous rocks, and were therefore deposited on a land surface which had to be depressed to permit the invasion of the sea and the accumulation of the Cretaceous marine deposits.

The thickness of these igneous rocks is unknown; we have not seen their base exposed. In each of the three localities where we studied them there was about 100 feet of them beneath the lowest beds of the sediments.

In the adjacent high Andes, there are igneous rocks of similar composition and alteration which probably belong to the same formation. Below we shall discuss the probability that the felsites, andesites, porphyries, granophyres and gabbros of the Río Pastaza, Río Papallacta and the Guacamayos mountains belong to the same series.

Río Coca Series

The twelve samples from the Río Coca were collected from massive rocks outcropping in the banks of the river at points from 56 to 61 miles above the mouth of the river and representing a surface from 1864 to 2050 feet above the sea. In the ascent of the Río Coca from its mouth for 56 miles the rocks are all sedimentary. They descend progressively to rocks of older age because of a gentle eastward inclination of the strata. At a point 56 miles from the mouth of the river the base of the sediments is underlaid by igneous rocks, and as far upstream as we were able to continue, to a point about 61 miles from the mouth, these igneous rocks form the bed of the river which here occupies a deep gorge walled with cliffs of sedimentary rocks.

Since the base of the igneous rocks is not visible, we do not know how thick they are or whether other sedimentary rocks underlie them or not.

The lowest of the igneous rocks, represented by samples 1-L and L-a, at elevation ± 2100 feet above the sea and about 61 miles from the mouth of the river, are volcanic fragmentals which occur as massive outcrops without any signs of stratification that we could see. Stratigraphically above these occur the rocks represented by sample No. 18, 60.5 miles above the mouth of the river, and by sample No. 2, secured at an elevation of 2008 feet, about 59 miles above the mouth of the river.

A highly tuffaceous andesite (Specimen No. 6), from the lower falls of the Río Coca, about 58 miles from the mouth and at an elevation of about 2000 feet, is found nearer the sediments.

Above this horizon, and represented by samples 1, 1a, 2, 3, 4 and 5, collected at an elevation of 1936 feet, about 58 miles from the mouth of the river, are altered trachy-andesite or latite tuff, and acid volcanic tuff, a spherulitic felsite, a volcanic tuff of about trachy-andesite make-up and a modified basalt. At this points the rocks are very massive, slightly stratified, and jointed.

The rock immediately underlying the sediments (No. 17) is a basaltic andesite.

Since nothing has been known heretofore of the geology of the isolated region from which these samples come, brief petrographic descriptions of them may be of some interest.

- ***Samples 1-L* and *L-a*** were taken farther up the canyon of the Río Coca and from a stratigraphically lower horizon than any of the other specimens of this series. They are very fine textured, strongly indurated, rocks and slightly weathered along joint surfaces. No. 1-L is gray and carries minute crystals of pyrite distributed along the joint planes. No. L-a is dark and very fine textured, but neither of them reveals its true character megascopically, because of changes brought about by the intense hydrothermal attack to which they have been subjected.

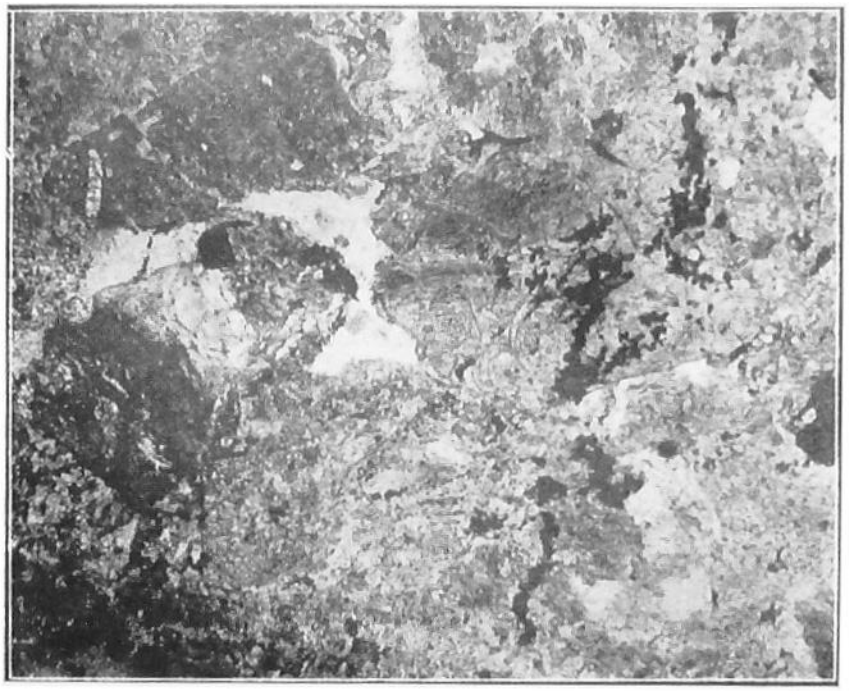

FIG. 9 – *Río Coca 1-L* – Devitrified acid volcanic tuff. Photomicrograph, ordinary light, showing clastic character. Note pearlitic glass fragments, and other glassy lava fragments. The black streak cutting the rock is an interrupted veinlet of pyrite. ×34.

Both of these rocks are volcanic fragmentals, but they differ somewhat in the nature of the fragments comprising them. No. 1-L is composed of acid volcanic glass fragments, including pieces of glass that are pumiceous, obsidian fragments with characteristic flow structure, pieces of pearlitic glass, and pieces of vitrophyre and other rock fragments, as well as many broken and much modified fragments of alkali feldspar and acid plagioclase. Crystals of magnetite and apatite are associated with some of the lithic fragments and veinlets of perfectly fresh pyrite cut all the structures in the rock, transecting many of the magnetite grains. All of the lithic and mineral fragments are closely packed in a small amount of groundmass that consisted initially of acid glassy ash, now thoroughly devitrified. In addition to the devitrification product of the finer glass particles, chlorite, hematite, dusty and granular magnetite, quartz and leucoxene, have developed as alteration effects.

The rock has been fractured likewise, and quartz, albite and pyrite were introduced. It is a devitrified, acid, volcanic tuff. Figure 9 illustrates the fragmental habit and the nature of the fragments.

- ***Sample No. L-a*** was initially a fine acid ash, carrying small, broken and angular pieces of quartz and both alkali and acid plagioclase feldspar. The chief modification product is a quartzose and feldspathic devitrification aggregate, although a little leucoxene, chlorite and sericite have likewise been produced. The texture has been coarsened by devitrification and many wholly modified remnants (“ghosts”) of shards of volcanic glass are distributed through the rock. It is a devitrified volcanic ash.

- ***Specimen No. 18***, from the next stratigraphically higher horizon and from a point 60.5 miles from the mouth of the Río Coca, elevation 2050 feet, is a strongly modified, indurated and slightly tuffaceous rock with trachytoid groundmass, whose phenocrysts consist of both acid plagioclase and alkali feldspar, some of which show partial saussuritization; whereas in others, zoisite, epidote, sericite and albite occur in separate individual grains and patches. In this specimen, also, the general groundmass is extremely patchy and different in aspect from place to place, yet aside from the obvious lithic fragments, which are much altered but readily recognizable as distinctly different lithic units, the various unlike areas in the groundmass merge into one another by imperceptible gradations. Thus, despite the patchy behavior, the rock appears to be of definitely pyrogenic rather than pyroclastic origin. The rock carries larger crystals of magnetite and apatite than the other rocks of this series. Small crystals of pyroxene, but of phenocrystic dimensions, are completely altered to serpentine, and in rare instances to a mixture of quartz, epidote, zoisite and serpentine. The rock is intermediate between the trachytes and andesites. It is a porphyritic latite or trachy-andesite, modified and indurated.

- ***Sample No. Z***, from 60 miles above the mouth of the Coca, elevation 2008 feet, represents a horizon nearer the sediments. It is a porphyritic rock with flow structure, initially of andesite make-up, but now completely modified and strongly indurated. The original, moderately basic, plagioclase phenocrysts are composed of mixed aggregates of coarse sericite, granular calcite, quartz, albite and epidote, all forming aggregate pseudomorphs after the original feldspar. Phenocrysts of original hornblende that initially was resorbed along the margins, have been altered to a mixture of calcite, epidote in fan-like, radiate acicular groups and a little quartz, all pseudomorphs after the former hornblende. The structures of the former resorbed margins are preserved as pseudomorphs composed of an opaque-white substance; this may be leucoxene derived from the alteration of possibly titaniferous granular magnetite that was formed during the resorption of the original hornblende.

The small plagioclase laths in the groundmass are likewise faithfully reproduced as mixed aggregate pseudomorphs, similar to the much larger phenocrysts of feldspar.

Patches of carbonate, containing perhaps a little iron and magnesia, in addition to lime, and small irregular areas of secondary aggregate-quartz, are scattered through the groundmass, products of the alteration of portions of it, and interstitial to the small groundmass feldspars. The rock contains also small irregular areas filled with chlorite and mosaic quartz, which suggest that leaching and filling were operative among the secondary processes which have affected the rock so profoundly. Most, if not all, of the primary substances have been destroyed. A few minute apatite crystals and euhedral grains of possible primary magnetite are the only originals remaining.

The rock consists now of coarse sericite, albite, quartz, calcite and other carbonate, epidote, zoisite, chlorite, leucoxene and a little hematite. The striking thing is the retention of the former structures in the rock notwithstanding the complete change of its substance. It is a meta-andesite.

- ***Specimen No. 6***, from a massive outcrop at the lower falls of the Río Coca, 58 miles from the mouth, elevation 2000 feet, represents the next horizon of these igneous rocks nearer to the sediments. This rock is so variable in texture from place to place that it is suggestive of a volcanic fragmental, but while there are a few distinct lithic fragments whose composition is different from the main part of the rock, most of the mass is andesitic. The groundmass changes in quality gradually; in some places there is a distinct pilitic structure common to andesites; other places exhibit a fine granular structure, and still other portions of the rock are more coarsely pilitic with good flow structure. All of these apparently different units grade into one another so there are no distinctly outlined individual fragments with the exception of those previously mentioned. It is difficult to say whether the rock was initially a volcanic tuff o somewhat uniform andesitic make-up, whose separate fragments have been obscured through alteration, or whether it is an andesitic lava that is strongly xenolithic and whose caught-up fragments have not only been sufficiently worked over to have lost their sharp outlines, but also still more obscured by alteration. The general aspect presented by the rock is that of a lava crowded with inclusions, some of which may be cognate inclusions, whereas others are distinct xenoliths of basaltic composition. These latter contain beautiful aggregate pseudomorphs of granular (mosaic) quartz after both pyroxene and olivine mixed in some cases with a little serpentine, and very irregular patches representing former cavities made by leaching, now filled with matted, acicular, greenish serpentinous aggregates that are almost isotropic, surrounded with much more strongly anisotropic matter that is composed of a mass of minute, interlocking scales, very much like fine sericite or talc, the whole margined with a very narrow strip containing fibers set perpendicular to the walls, resembling chrysotile in habit. Some of the patches carry feldspar phenocrysts which have been in part altered to quartz, sericite, zoisite-epidote and albite, and occasional phenocrysts of feldspar contain channels, formed perhaps by leaching, filled with the same fine serpentinous aggregate just described.

More or less leucoxene, granular titanite, chlorite, magnetite and limonitic matter are distributed through the rock in finely granular aggregates. The sample represents either a strongly indurated and modified, but remarkably uniform, andesitic tuff, or a highly tuffaceous andesite. It is probably the latter.

Comment on Analysis*:* A comparison of the chemical analysis of this rock with the average analysis of twelve andesites shows that both silica and alumina are appreciably higher in Río Coca No. 6, and both lime and magnesia are considerably lower. There is less than half the amount of lime in the Río Coca sample than is shown in the average andesite, and approximately but three-fourths as much magnesia. While the potash and soda, lower and higher respectively in the Río Coca sample, differ from the average andesite, they are nevertheless within the range of variation shown by the andesites themselves. The total iron content is higher in the average andesite, and manganous oxide lower; the greater part of the iron in the Río Coca sample is present in the higher state of oxidation, and the manganous oxide is rather high. Considering the altered condition of the rock, it corresponds fairly well with the composition of andesites in general.

The next higher horizon in these igneous rocks is represented by samples Nos. 1, 1-a, 2, 3, 4 and 5, from a point of 58 miles from the mouth, elevation 1936 feet. The outcrop is massive, possibly slightly stratified, jointed, and containing inclusions. They are all intensely altered, a condition common to every one of the Río Coca samples. Nos. 1 and 1-a represent material a few feet higher stratigraphically than Nos. 2 and 3.

- ***Sample No. 1*** is very slightly porphyritic, with a trachytoid fabric, the feldspars consisting of plagioclase laths distributed among crystals of alkali feldspars that are somewhat larger than the plagioclase laths, but not of phenocrystic dimensions. All the feldspar is altered. Sparingly distributed granules of former pyroxene have been converted into a mixed modification-aggregate consisting of serpentine and chlorite. The rock is essentially an altered trachy-andesite, or latite.

- ***Specimen No. 1-a*** is much more obscure. It carries feldspar crystals that seem to be phenocrysts, but the rock is either strongly tuffaceous or else a real fragmental. The phenocrysts of feldspar are chiefly of the alkali type, although acid plagioclase is present among them. All of them are mor or less sericitized, and occasionally granules of epidote appear as one of their modification products. Many of them exhibit a streaked and patchy appearance common to feldspar that has been partially albitized, and these feldspars are judged to have been modified by sericitization, albitization and, to a very slight degree, by epidotization.

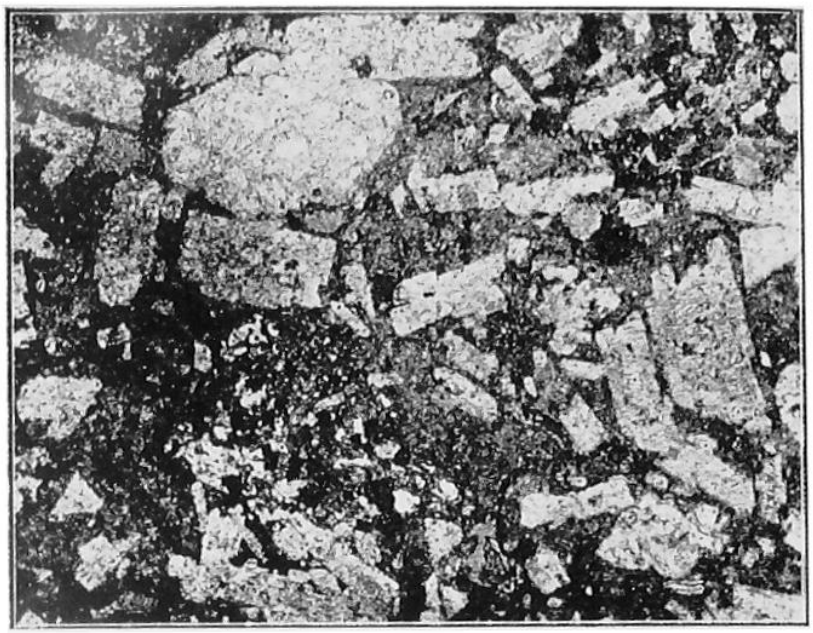

FIG. 10 – *Río Coca No. 1a* – Tuffaceous and porphyritic latite. Photomicrograph, ordinary light, showing the very obscurely fragmental habit, porphyritic structure and groups of partially albitized feldspar phenocrysts. The rock is highly variable in texture and groundmass habit from place to place and very strongly tuffaceous, but the fragments or xenoliths are so much modified that they merge into one another, and are only indistinctly outlined. ×24.

The groundmass of the rock is extremely variable, changing in texture, structure and in composition from place to place. Some areas exhibit typical hyalopilitic structures characteristic of andesites; other places are finely felsitic, almost glassy, with minute feldspars and fragments of crystals distributed in them; and still other areas, felsitic or finely granular, carry feldspar phenocrysts themselves, suggesting fragments of a porphyritic volcanic of some sort. Yet, with a few exceptions, these areas are not sharply outlined; they have all been obscured through alteration and they merge imperceptibly into one another.

Coarsely crystalline epidote, mixed with zoisite and quartz, forms aggregate pseudomorphs after pyroxene, both single and grouped; the grouped pseudomorphs carry numerous included euhedral grains of magnetite.

There are indistinctly outlined areas in the rock composed of epidote and zoisite, suggestive of possible basic lithic fragments that have been completely destroyed by alteration; and non-pleochroic, light-green serpentine aggregates pseudomorphous after forms suggestive of hornblende.

The rock is judged to be a very much altered, strongly indurated, obscurely fragmental or strongly tuffaceous volcanic with the composition of trachy-andesite or latite; essentially it is an extensively altered, tuffaceous and porphyritic latite. Figure 10 illustrates this rock.

- ***Specimen No. 2*** is lower stratigraphically than No. 1, and pyroclastic in origin. It is composed of fragments of obsidian with flow structures, pieces of pearlitic glass, and fragments of vitrophyre and keratophyre, all very much altered. Many broken crystals of both alkali feldspar and plagioclase are contained in the rock, some partially, others almost completely, altered to mixed aggregates consisting of sericite, patches of albite and granular epidote. Considerable epidote and a little calcite occur all through the rock, and much mosaic quartz has developed through the silicification of some of the lithic fragments whose former pearlitic, pumiceous and flow structures are retained only as “ghost” or inherited structures. Minute fractures in the rock are filled with quartz, calcite and epidote.

It is an indurated, intensely modified, moderately acid volcanic tuff, with the composition of a trachyte or latite.

- ***Specimen No. 3***, taken from the neighborhood of No. 2, is a fine, thoroughly devitrified, spherulitic felsite; probably a devitrified spherulitic glassy lava originally, fractured and healed with quartz, which not only fills the fractures but which also encroaches on the substance of the rock as well. The primary spherulitic structure exists now as a relic or “ghost” structure, since the rock has been very extensively modified.

- ***Specimens Nos. 4* and *5***, taken from the same vicinity as Nos. 1, 1-a, 2, and 3, are different in initial make-up, although they have suffered in the same way as the others from intense hydrothermal attack. ***Sample No. 4*** is of pyroclastic origin, carrying many fragments of various sorts of igneous rock, ranging from acid pearlitic lavas to pieces of andesitic rock, and fragments of broken feldspars. All the fragments are much altered; chlorite, serpentine, epidote, quartz, magnetite and leucoxene are the dominant secondary substances, and the rock has also been silicified to some degree through the introduction of quartz.

The original clastic character of the rock has been considerably obscured by these changes; the same set of products has developed in the initially fine groundmass in which the lithic fragments are distributed, and rather extensive devitrification has likewise been brought about. It is essentially a much-modified volcanic tuff of about trachy-andesite make-up.

- ***Sample No. 5***, from the same vicinity as No. 4, is very different from No. 4, and from all the preceding samples of the Río Coca series. It is very strongly porphyritic, the larger phenocrysts consisting of augite, much fractured within the crystals, which contain areas that are somewhat granular. The augite crystals have a habit of close grouping, so that aggregate or compound phenocryst composed of closely knit but differently oriented units result.

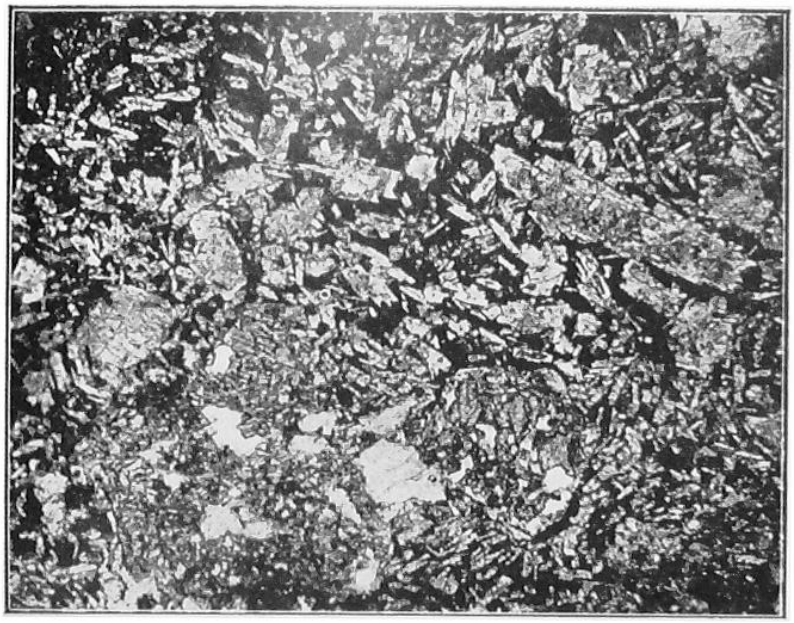

FIG. 11 – *Río Coca No. 5* – Modified Basalt. Photomicrograph, ordinary light, showing strongly modified feldspars, and aggregate pseudomorphs of epidote, quartz, calcite and penninite after augite (in the lower part of the picture). The black groundmass in which all the crystals are distributed is basic glass, now partially altered to an opaque white product judged to be anauxite. ×24.

The birefringence of the augite does not exceed 0.030, the pleochroism is imperceptible and $Z \wedge c$ is approximately 45°. Some of the augite crystals are wholly altered, others only slightly altered; the alteration products are epidote, quartz, penninite and calcite. Penninite, occasionally mixed with a little calcite and quartz, likewise occurs pseudomorphous after olivine; the crystals (pseudomorphs) are smaller than the augite and frequently sharply idiomorphic.

The plagioclase, both as phenocrysts and as small laths distributed in the groundmass, is labradorite. It has been mor or less modified, however, so that it consists in part of alteration aggregates composed of fine mixed sericite, epidote, carbonate, and zoisite.

Interstitial basic glass forms part of the groundmass of the rock, but it appears opaque white in thin section, consisting now of one of the kaolin minerals, probably anauxite. The general character of the rock is shown in Figure 11; the black interstitial groundmass is really opaque white by reflected light. The rock is a modified basalt.

- ***Specimen No. 17***. Immediately underlying the sediments occurs igneous rock presented by Sample No. 17, collected at a point 56.5 miles from the mouth of the Río Coca, at an elevation of 1864 feet. The outcrop is massive and vein-streaked. This very fine textured black rock is slightly porphyritic with a beautiful fluxion structure emphasized by microlites of labradorite, which are not greatly modified, set in a mesostasis of glass. The phenocrysts consist of colorless pyroxene, resembling in optical and structural characters that described as occurring in Sample No. 5; and mixed pseudomorphs of limonite, carbonate and chalcedony after olivine.

As in Specimen No. 5, several units of pyroxene form closely knit groups, each individual of the group having a different orientation, making compound phenocrysts. In most cases several, sometimes each one, of these units have been partly altered to clear granular carbonate, probably calcite, different in appearance and behavior from the carbonate that is contained within the destroyed olivine crystals and which is distributed in patches all through the groundmass of the rock in the form of a very finely granular aggregate with a turbid aspect, quite unlike the large clear calcite grains in the pyroxene. A number of small fractures, filled with later mosaic-quartz and calcite, transect the rock, cutting through groundmass, carbonated patches in the groundmass, and phenocrysts, indifferently. The specimen is on the border between andesites and basalts; it is strongly feldspathic and possesses the characteristic hyalopilitic fabric of andesite, but the ferromagnesian components are pyroxene and olivine and the feldspar is labradorite. It is essentially a basaltic andesite. Figure 12 illustrates this rock.

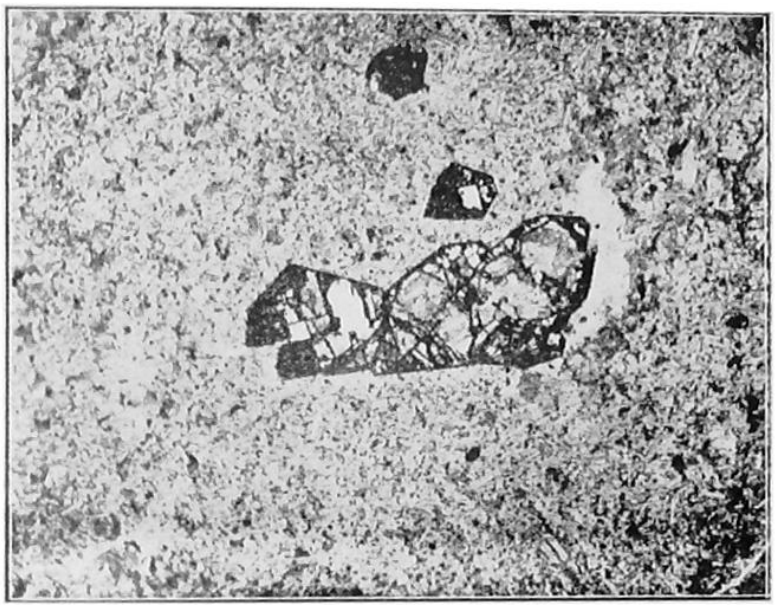

FIG. 12 – *Río Coca No. 17* – Basaltic andesite. Photomicrograph, ordinary light, showing tiny labradorite microlites in fluxion structure, and one of the completely altered olivine phenocrysts. These consist of mixed aggregates of limonite, carbonate and chalcedony, pseudomorphs after the original olivine. ×24.

Río Misahuallí Series

About sixty-two miles in an air-line southwest of the Río Coca volcanics, and also underlying almost-horizontal sediments, some of them of proved Albian age, there is another series of altered volcanics of unknown thickness; their base is not exposed. These outcrop in the bottom of another deep canyon, that of Río Misahuallí, at an elevation of about 1500 feet.

About 100 feet of these rocks are exposed at the river surface. At this locality marine limestones of Albian age are separated from the underlying volcanics by about 400 feet of sandstone, which is absent on the Río Coca at the same horizon. We do not know whether any pre-Albian sediments are represented here or not. As in the Río Coca series the underlying volcanics represent flows and tuffs, now greatly altered, all of which are certainly much older than the Albian.

- ***Sample No. 73***. The rock immediately underlying the sediments and corresponding in horizon to the basaltic andesite (Specimen No. 17) of the Río Coca, is exposed in cliffs composed of massive grayish-pink to yellowish streaked rock. The sample, which was collected on October 11, 1921, was secured from a place about three miles below the mouth of the Río Hollín.

The specimen is somewhat obscurely fragmental and considerably altered. The most conspicuous fragments are those in which alteration has produced both hematite and limonite; these stand out sharply from the mor obscure fragments in which alteration has taken other forms.

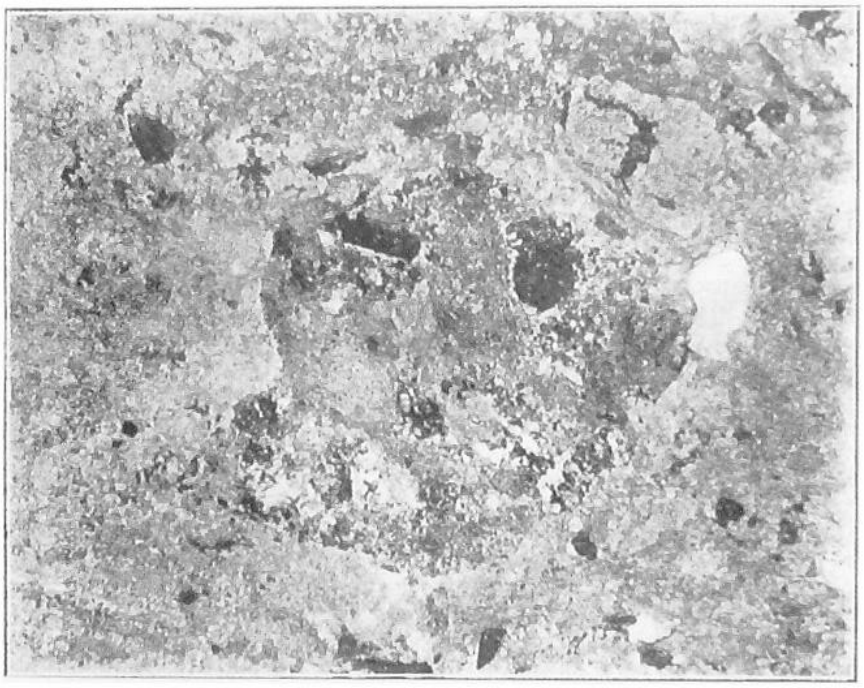

FIG. 13 – *Río Misahuallí No. 73* – Dellenitic tuff. Photomicrograph, ordinary light, showing one of the more prominently outlined andesite fragments, and other fragments, very much obscure, owing to the extensive alteration. The small white patch on the right of the large fragment is quartz. ×24.

The fragments consist of andesite, whose interstitial groundmass is thoroughly altered and heavily charged with hematite, and whose feldspar microlites are also modified; altered pieces of vitrophyre, some charged with hematite, others stained by limonitic products, pieces of much altered basaltic vitrophyre, pieces of keratophyre not so badly modified, pieces of dacite carrying phenocrysts of plagioclase and small corroded phenocrysts of quartz; broken crystals of orthoclase, slightly sericitized, large crystals of plagioclase of oligoclase-andesine composition, usually more or less fractured, slightly sericitized, stained with limonite and charged with hematite; thoroughly altered biotite crystals and broken hornblende, almost completely converted to mixed hematite-limonite; and much secondary quartz in fine grains and patches of fine mosaic-like aggregates. Crystals of modified titanite and limonite pseudomorphs after pyrite are sparingly distributed through the general groundmass. The rock as a whole is stained with limonite and contains streaks and patches of hematite, kaolinitic matter and leucoxene.

It is difficult to classify a mixed fragmental of this character; the average composition of the rock is judged to be intermediate between the rhyolites and dacites, and for all practical purposes it may be regarded as a very much modified dellenitic tuff.

Figure 13 shows one of the more conspicuous fragments, that stands out prominently from the more obscure fragments surrounding it.

- ***Specimens A* and *69*** were collected immediately underneath the dellenitic tuff (Sample 73) just described, two miles farther up the Misahuallí River, and about one mile below the mouth of the Hollín River.

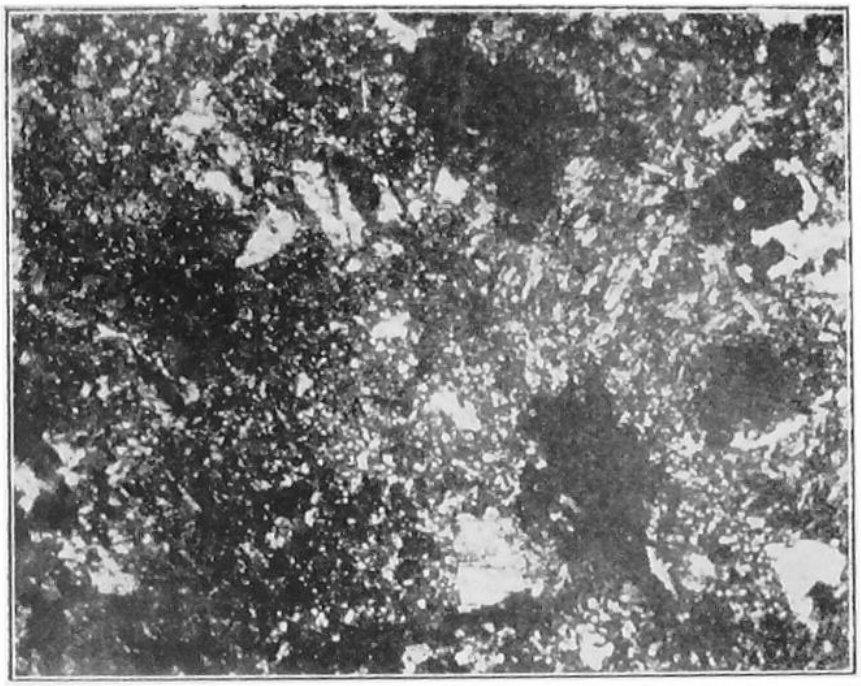

FIG 14 – *Río Misahuallí No. A* – Indurated, altered tuffaceous trachytic felsophyre. Photomicrograph, nicols crossed, showing the strongly silicified condition of the rock. Most of the small white specks are quartz of secondary origin. The larger white patches are feldspar, the black ragged patches are holes in the section. ×60.

- ***Sample A*** has a finely felsitic groundmass in which microphenocrysts of feldspar are distributed. Orthoclase, microperthite, and plagioclase that has the composition of oligoclase-albite, as nearly as could be determined, are all represented among the tiny feldspar crystals. They have all been more or less modified. Ferromagnesians are almost lacking in the rock; the few crystals consist of bleached biotite carrying little granules of zoisite and patches of leucoxene.

Very small xenoliths are sparingly scattered through the groundmass, which is somewhat variable in habit from place to place, but this feature is rather obscure owing to alteration and to the development of fine secondary quartz.

The rock is undoubtedly tuffaceous, if not actually fragmental; it has the general composition of a trachyte, but it lacks the structure characteristic of true trachytes. It is essentially an exceedingly fine textured, altered and tuffaceous trachytic felsophyre, or possibly a modified and strongly indurated trachytic ash.

The fine texture of the rock, its altered condition, and the abundance of fine secondary quartz, are shown in Figure 14.

- ***Sample 69*** is also finely felsitic, with a few small completely kaolinized microphenocrysts of feldspar and an occasional bleached and completely modified biotite crystal distributed through the groundmass, which is composed almost wholly of a micro-granular, interlocking aggregate of alkalic feldspar, minutely micrographic in places, very slightly sericitized, containing minute, scattered patches of carbonate and a little secondary quartz.

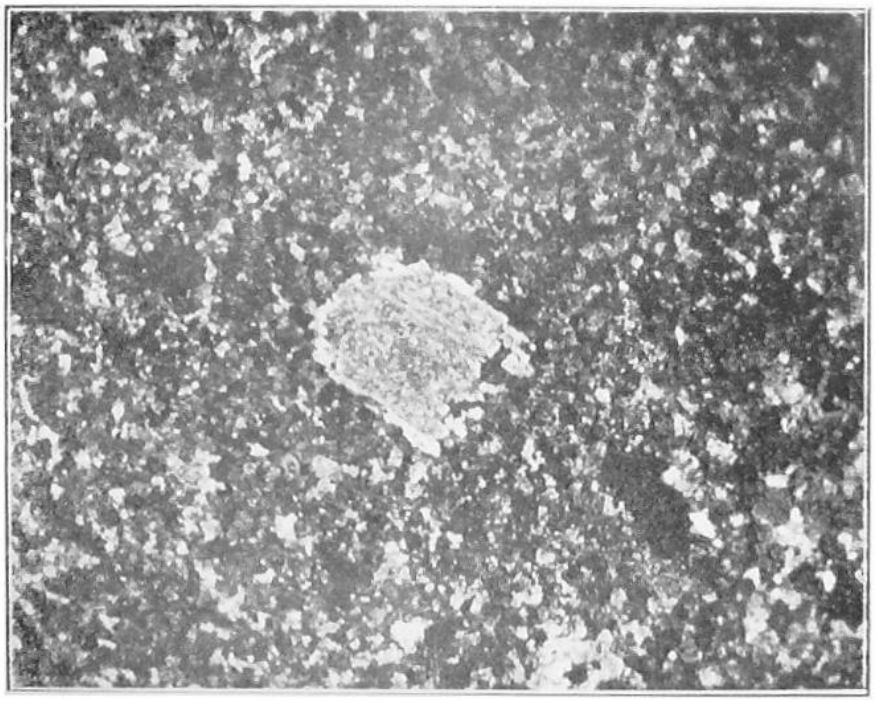

FIG. 15 – *Río Misahuallí No. 69* – Altered trachytic felsophyre. Photomicrograph, nicols crossed, showing altered feldspar phenocryst and microgranular groundmass of feldspar. ×60.

The rock is veined with calcite with which is associated a little pyrite and what appears to have been siderite that has been entirely altered to mixed red-black hematite and to carbonate.

This sample is essentially the same as Sample A in general composition, but the groundmass is much more uniform both in structure and texture, and there is no suggestion of fragmental habit at all. It is essentially a trachytic felsophyre.

Some of the features mentioned are illustrated in Figure 15, which shows the microgranular character of the groundmass and one of the kaolinized and slightly sericitized little feldspar crystals.

- ***Specimens 71, 71-a, 71-b and 72*** represent the lowest formations, stratigraphically, encountered on the Misahuallí River. The samples were taken from an outcrop along the river about two miles below the mouth of the Hollín River. The rocks here dip 10° west, upstream. In the field the weathered exposure strongly resembles a conglomerate, containing rounded "pebbles" up to two or three inches in diameter. These "pebbles", however, proved to be amygdaloidal fillings in an originally extremely porous basalt.

- ***Samples 71, 71-a, 71-b*** are different specimens taken from the same formation. the rock is composed of small plagioclase laths and somewhat larger crystals of the same substance, all very considerably modified. The alteration is saussuritic in character, consisting of patches of sericite, chlorite and excessively finely microgranular zoisite distributed in new and more acid feldspar than that which originally composed the laths.

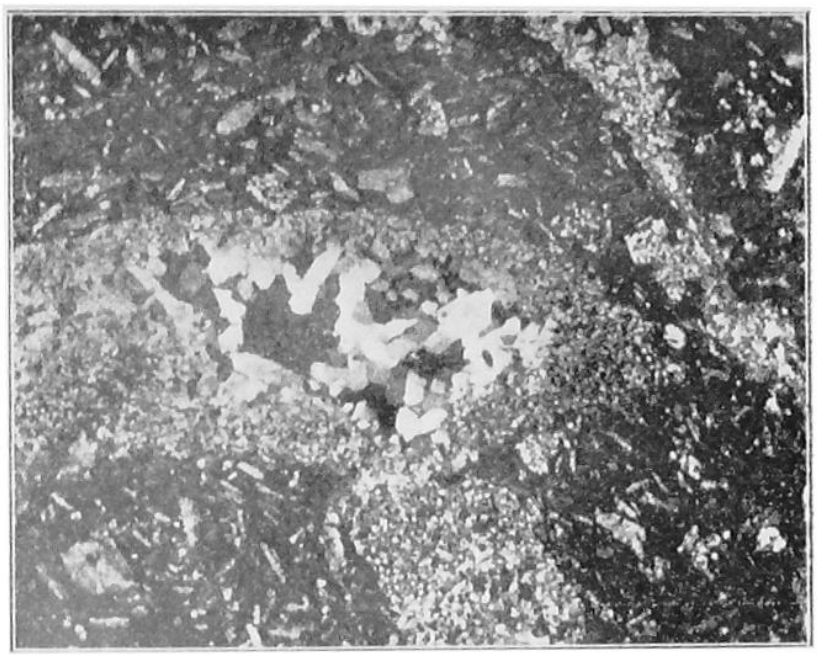

FIG. 16 – *Río Misahuallí No. 71* – Altered basaltic amygdaloid. Photomicrograph, nicols crossed, showing ovoid or lenticular amygdule of aggregate quartz, quartz pseudomorphous after pyroxene, completely altered feldspar and dark altered glassy groundmass. ×21.

Much larger crystals of phenocrystic dimensions have been altered to mosaic-like aggregates of quartz, mixed with faintly green mica, the whole forming beautifully pseudomorphic aggregates after what is judged to have been originally pyroxene. Small olivine crystals, now consisting of an alteration complex of various forms of serpentine, mixed with carbonate, are sparsely disseminate through the groundmass, which consists of brown basic glass, in which all of the altered crystals mentioned above are distributed. Some of the vesicles are filled with quartz in the form of both mosaic-like aggregates and feathery chalcedony, mixed, in some cases, with carbonate and zeolites, and others are filled with carbonate. Quartz and chalcedony form the major part of the fillings, so that the round and ovoid amygdules, being much more resistant to weathering than the rock itself, have weathered in relief, thus giving the rock the aspect of a conglomerate in the field.

Little cubes of pyrite, some still unaltered, others partially and wholly converted to limonite, are associated with the mosaic-like quartz aggregates pseudomorphous after pyroxene previously mentioned, and veinlets of mixed quartz-chalcedony traverse the rock, containing as part of the mixed vein-filling a black metallic mineral of some sort not determinable in thin section. Extremely irregular cavities, evidently produced by leaching are also filled with the quartz-chalcedony aggregate similar to that which occupies the primary vesicles. The brown, basic, glassy groundmass is itself altered to a translucent product, white by reflected light, and presumably of kaolinitic nature, although the “glassy” groundmass is still brownish in color by transmitted light.

The rock is an altered, glassy basaltic amygdaloid, rather uncommonly vesicular originally, containing abundant amygdules of considerable size.

- ***Sample 72 (a-b and c)*** was secured in the same locality as Sample 71, and represents the same formation. It is similar to No. 71 in composition, structure and alteration effects, but carbonate as a secondary product is much more prominent than in No. 71. Irregular leaching cavities, now filled, are more numerous in this sample, but the rock is not much different otherwise.

The plagioclase is greatly altered and original pyroxene and olivine are entirely destroyed; they are represented now by complex aggregate pseudomorphs consisting of quartz, carbonate, serpentine and limonitic products, and the initially glassy groundmass is more or less kaolinized and stained with limonite. Figures 16 and 17 illustrate different specimens of this rock.

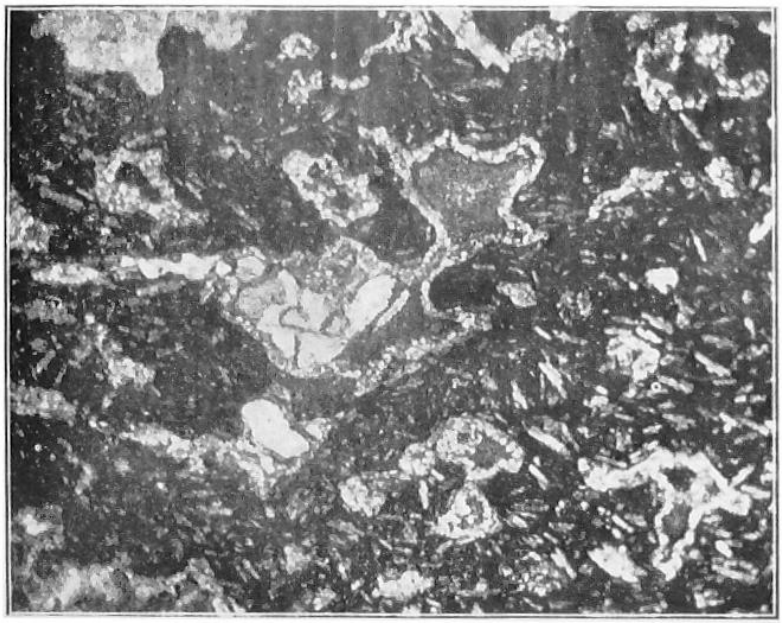

FIG. 17 – *Río Misahuallí No. 72-b* – Altered amygdaloidal basalt. Photomicrograph, nicols crossed, showing cavities formed by leaching, filled in part with calcite, in part with fine serpentinous matter; and completely altered feldspar laths distributed in an altered, dark, glassy base. ×21.

Río Jandache Series

The third place where the base of the sediments and the underlying igneous rocks were encountered is about 20 miles north of the occurrence on the Misahuallí River and about 50 miles in air-line southwest of the Coca River locality.

Here the sediments terminate against the Guacamayos mountains at an elevation of 4000 feet above sea level. They form cliffs in the valley of the Jandache River where the trail from Quito to the Napo River crosses the valley.

The presence of these sediments, and the underlying igneous rocks similar in character to the volcanic rocks and associated overlying sediments found at the Coca River and the Misahuallí River, afford additional evidence of the existence of a widely distributed sedimentary series lying unconformably on a series of much older, altered igneous rocks of surface volcanic types.

- ***Specimen B***, collected from the cliffs and beneath the sediments of the Jandache River, is a spherulitic, porphyritic and devitrified lava, with a composition intermediate between a rhyolite and dacite.

FIG. 18 – *Río Jandache No. B* – Devitrified altered dellenitic vitrophyre. Photomicrograph, ordinary light, showing fine and originally glassy microlite groundmass, with flowage and traces of spherulites, and an altered orthoclase phenocryst. ×25.

The rock was initially a porphyritic glass containing spherulites, small phenocrysts of oligoclase and orthoclase, little biotite crystals now thoroughly bleached and spotted with magnetite, limonite, leucoxene and hematite, and multitudes of crystallites distributed through the originally glassy groundmass in swirling flow lines. The primarily glassy groundmass consists of an unusually coarse and intricately interlocked devitrification aggregate composed of quartz and feldspar, which retains traces of replaced spherulites and through which the lines and streams of crystallites pass uninterruptedly.

The feldspar phenocrysts are slightly kaolinized and flecked with tiny scales of sericite, and a few small hornblende crystals in the groundmass have been so thoroughly destroyed by the alteration attack that only their outlines remain. They consist now of an aggregate of quartz mixed with a little fine flaky mica and limonite. The rock is a coarsely devitrified dellenitic vitrophyre. Some of the features mentioned are shown in Figure 18 and 19.

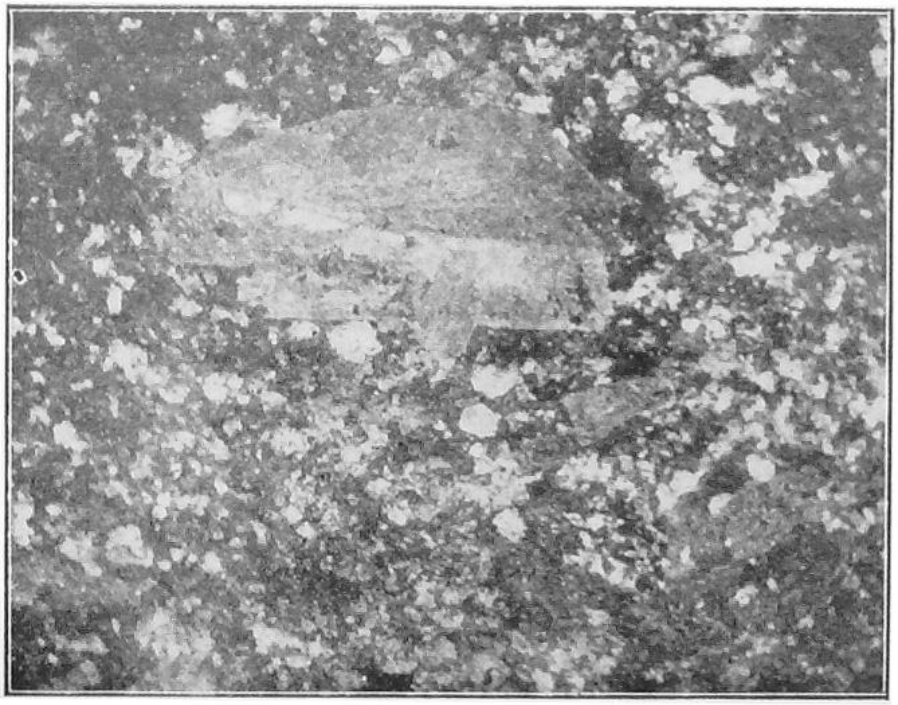

FIG. 19 – *Río Jandache No. B* – Photomicrograph, same field seen in Fig. 18, nicols crossed, showing complete devitrification of the former glassy groundmass, and altered phenocryst of orthoclase. ×21.

b. Igneous rocks of probable pre-Albian age

Río Pastaza Series

In the gorge of the Pastaza River, between the mouth of Río Topo, which lies at an elevation of 4000 feet, and the hamlet of Mera, 3800 feet above sea level, 47 miles and 56 miles, respectively by trail from the city of Ambato, there is a narrow belt of igneous rocks nine miles in width, lying between exposures of sediments, on the one end at the mouth of the Topo River and on the other just east of the village of Mera.

The sediments at Topo River are limestones, shales and sandstones, containing fossils. A good collection of these was made but it was unfortunately lost in transit. We believe these rocks are Cretaceous. They dip westward at an angle of 55°, striking nearly north-south. The sediments just east of the village of Mera are Cretaceous.

On the east bank of the Topo River there are blocks of reddish granite, and exposures of this granite occur in Zuñac creek, which lies a mile to the east. The granite may be traced as far as a hut called "Tamba de Cashaurcu", 7.75 miles by trail from the Topo River, and lying at an elevation of 4674 feet above sea level. In the midst of the granite, which apparently forms the surface almost as far as the village of Mera, and between a high ridge to the eastward known as Abitagua and a point about one and a half hours' walk from the hut called Cashaurcu, there is an outcrop of igneous rock of surface volcanic type, resembling the previously described pre-Albian rocks of the Coca, Misahuallí and Jandache Rivers.

Since this exposure is not directly associated with any of the sediments the age of these volcanics is unknown.

- ***Specimens 7a* and *7c*** were secured from the exposure mentioned, on the north side of the Pastaza Valley about three miles west of Mera.

- ***Sample 7a*** is coarsely felsitic in texture. It is composed of dominant alkali feldspar and quartz in beautiful micrographic intergrowths, occasional slightly larger individual allotriomorphic quartz grains and small patches of mosaic-like aggregates of quartz, the whole forming over 95 per cent of the rock. Tiny shred of chloritized biotite and a few chloritized crystals of the same mineral, of phenocrystic dimensions, are scattered through the groundmass, together with a few small aggregate patches of zoisite-epidote. The most striking thing about the rock is its micrographic structure. Minute euhedral crystals of plagioclase feldspar, of acid oligoclase composition, are set in poikilitic fashion in individual micrographic areas, different sections of which extinguish differently so that the micrographic units simulate crude and extremely coarse spherulites.

In composition the rock is a rhyolite, although it lacks flow structure.

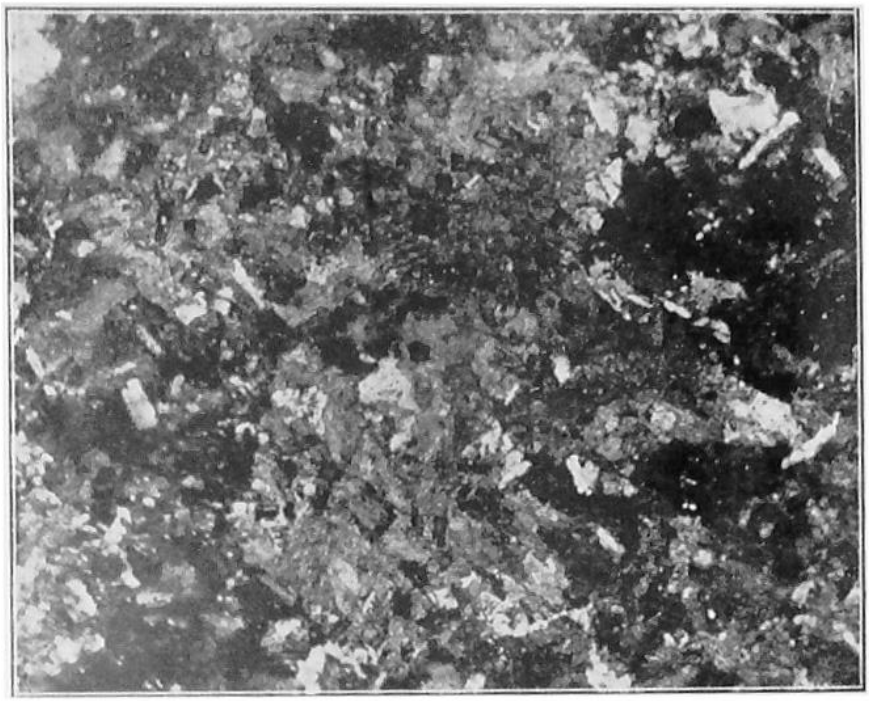

FIG. 20 – *Pastaza Valley No 7a* – Rhyolite. Photomicrograph, nicols crossed, showing finely micrographic quartz-feldspar groundmass containing small euhedral laths of oligoclase in the micrographic areas, and anhedral grains of quartz. ×60.

- ***Sample 7c*** is finer textured than No. 7a, and lacks the very striking micrographic structure displayed by that specimen. The groundmass consists of a closely interlocking fine aggregate of alkali feldspar, carrying numerous fine scales of sericite. Both orthoclase and acid oligoclase occur as phenocrysts, as well as corroded quartz crystals. A few bleached biotite crystals spotted with little patches of leucoxene represent the only other component in the rock. Like No. 7a, this specimen is a simple rhyolite, lacking flow structure. Figures 20 and 21 illustrates these two rocks.

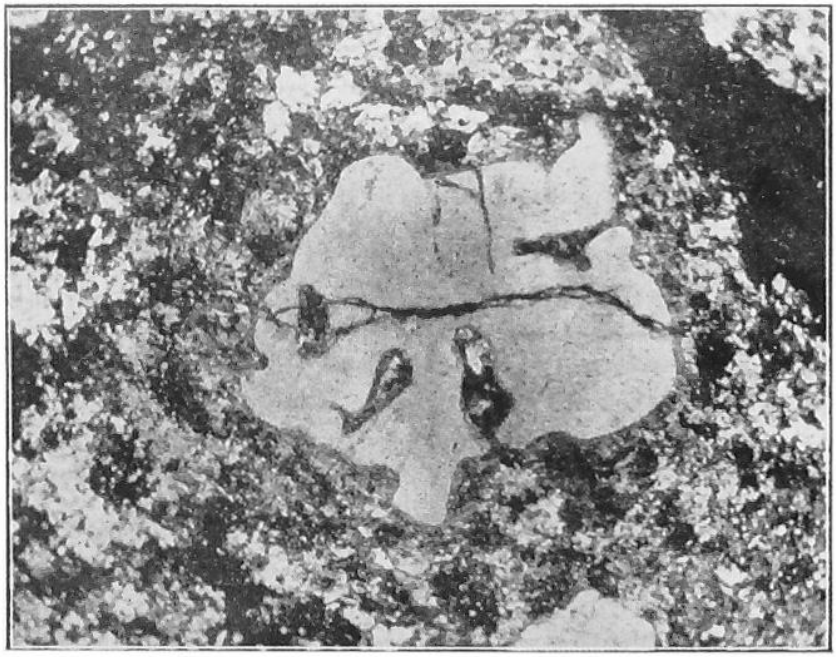

FIG. 21 – *Pastaza Valley No. 7c* – Rhyolite. Photomicrograph, nicols crossed, showing partially resorbed quartz phenocryst and groundmass of fine, interlocking microcrystalline aggregate of feldspar, more or less sericitized. ×60.

"Cordillera" Guacamayos Series

- ***Specimen A, B* and C**. About twelve miles, in an air-line, south of the village of Baeza on the trail to the Napo River there is a prominent but narrow ridge whose crest rises to an elevation of 7870 feet above the sea. Six miles south of this summit, at the base of the ridge, the trail crosses the Río Jandache where, as previously mentioned, the pre-Albian sediments terminate in the south slope of the valley and are underlain by altered volcanics.

The rocks of the "Cordillera" Guacamayos, probably of the same age as the pre-Albian volcanics, are badly weathered, rusty, brown and white mottled, and contain chalky white spots.

- Although ***Specimen A*** is very much altered there are distinct traces left of its former texture and structure. It is coarsely porphyritic, with large phenocrysts of altered plagioclase feldspar and Carlsbad twins of alkali feldspar distributed in a moderately coarsely crystalline groundmass composed of smaller laths of altered plagioclase, and plates of bleached biotite. Larger crystals of biotite, of phenocrystic dimensions, are likewise distributed through the rock. Most of the feldspar is thoroughly altered; all of it has been sericitized and a great deal of it has been albitized. The rock has been flooded with quartz and albite to such a degree that the original groundmass-feldspar laths, now almost wholly modified in composition, are distributed in a much coarser textured mosaic of albite and quartz, which is filled with "dust" outlining the forms of the earlier replaced feldspar, and with bubble and liquid inclusions as well.

Here and there albite twinning may be observed in some of the feldspar phenocrysts, but the clear feldspars of the phenocrysts are crowded with bubble and liquid inclusions; this feldspar is judged to be later replacement albite. All the biotite is bleached, wholly or in large part, with the development of brilliantly polarizing colorless mica, a faintly green pleochroic mica that is also brilliantly polarizing, a little granular titanite, granular magnetite, and a little leucoxene. Fine flaky chlorite is also a product of the same process.

There is no evidence of crushing or shearing, but the rock is so thoroughly modified by processes that were under igneous control that provided the extent of this sort of modification may be considered a criterion, this rock belongs to the older group; that is, it is probably older than the late Andean lavas (pre-Quaternary). Weathering has produced limonitic and kaolinitic products, subsequent to the modification of the rock by the metasomatic replacement by quartz and albite. A little of the quartz may be primary, more especially in scattered areas where it has an interstitial distribution. It is almost impossible to differentiate, however, between original quartz and that which is associated with the albite as replacement quartz. So far as can be judged the rock is a much modified and extensively weathered monzonite porphyry, or a closely related type.

- ***Sample B***. This specimen carries, phenocrysts of embayed quartz, in many instances surrounded by and in all cases connected with and encroached upon by very coarsely spherulitic feldspar, which is associated not only with the quartz phenocrysts but which also occurs in close connection with the feldspar phenocrysts as well. Very much smaller spherulites with the same composition are distributed all through the granular quartz-feldspar groundmass.

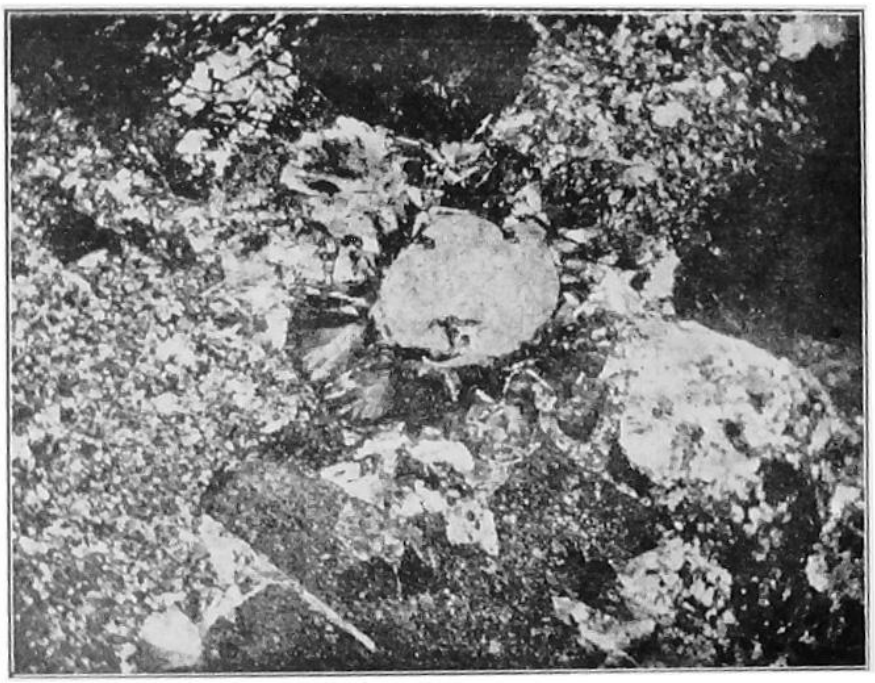

FIG. 22 – *Cordillera Guacamayos No. B* – Spherulitic granophyre. Photomicrograph, nicols crossed, showing granular groundmass of quartz-feldspar, altered feldspar phenocrysts and a spherulitic area with center of quartz. The dark crystals at top and right of picture are altered, very turbid and sericitized phenocrysts of feldspar. The rock is strongly porphyritic. ×20.

The feldspars, both as phenocrysts and in the groundmass, are almost completely altered; in part to fine flaky sericite; in part to an opaque-white finely granular product that causes the feldspar to look very dark and turbid by transmitted light, probably a form of kaolinite; and in part to a low index, transparent but milky isotropic substance that may perhaps be halloysite (?). The feldspars still show traces of both albite and Carlsbad twinning; they are judged to have been initially both orthoclase and soda plagioclase.

The biotite has been wholly destroyed and converted into aggregate granular pseudomorphs of quartz, epidote, chlorite, magnetite and leucoxene. Superficial weathering has been productive of limonite, which has formed at the expense of some of the biotite, and which is likewise distributed in minute cracks in the rock. The halloysite (?) and the other opaque-white alteration product of the feldspars are likewise judged to be superficial weathering products. The rock is a spherulitic granophyre.

Figure 22, a photomicrograph taken with nicols crossed, illustrates the coarsely spherulitic character of the rocks, its porphyritic habit, and the moderately granular condition of parts of the groundmass that are not spherulitic.

- ***Sample C*** has been much more affected by weathering than either A or B. It is a granitoid rock whose feldspar, now almost completely destroyed, was a basic or moderately basic plagioclase. The original ferromagnesian has been entirely converted into a brilliantly polarizing, brownish yellow, slightly pleochroic fibrous and scaly aggregate judged to be goethite, which is distributed along the cleavages of the feldspar and in the body of the feldspar itself in fan-like groups of fibers, as well as interstitially. Much epidote and secondary quartz have developed through the alteration of the feldspars, so that the rock now consists largely of secondary aggregates and products of weathering. From the remnants of originals left and the nature of the alteration substances, the rock is judged to be a gabbro, or an allied type.

All of these samples are probably related to an earlier igneous stage than that which gave birth to the later lavas. There is no evidence, however, of any of the severe deformation that has affected the schists series of the Papallacta group.

Río Papallacta Volcanics (pre-Albian?)

In the midst of the schists of the Río Papallacta, 6.7 miles east of Papallacta, at an elevation of 8571 feet, there is an outcrop of apparently the same formation as that underlying the Albian sediments.

- ***Specimen 2b***, representative of this outcrop, is a very fine textured, pinkish, and much indurated rock.

Although all the original minerals have been completely destroyed both texture and structure are beautifully preserved. Some of the lath-like feldspar and some of the originally fine interstitial groundmass have been converted into a very fine microcrystalline aggregate whose index of refraction is higher than that of the associated quartz; it is judged to be microcrystalline kaolinite. The femic components of the rock have been altered to limonite and turbid carbonate, appearing in ragged patches but also pseudomorphous after small prismoids of some sort, probably either augite or hornblende. The complete destruction of the components, but at the same time the preservation of their original form and distribution, is a very striking feature.

Much quartz of secondary origin is a prominent component of the rock, and this has replaced both groundmass and feldspar. Judging from the relations between the quartz and kaolinite, the quartz is earlier; the kaolinite actually encroaches on the quartz and in many instances, it has completely replaced the secondary quartz, so that the substance of the groundmass and former feldspar is entirely kaolinite; whereas in other areas the replacement of the quartz by kaolinite is partial, the former feldspars consisting of both products. In places where the quartz is the chief replacing medium, the lath-like feldspars are structurally suggestive of former plagioclase.

FIG. 23 – *Papallacta River Volcanic No. 2b* – Photomicrograph, ordinary light, showing relic structure. The feldspars are merely "ghosts" of original plagioclase laths. They are so completely replaced by quartz and kaolinite that all traces of them disappear between crossed nicols. The interstitial groundmass has been altered to the microcrystalline kaolinite and quartz. The black patches are limonite. ×24.

The rock was probably initially an andesite or some closely related type, which was thoroughly silicified and partially kaolinized. It is certainly later than the schists, but whether it may be related to some of the late Andean lavas or not it is impossible to say.

Figure 23, a photomicrograph taken in ordinary light, illustrates the feldspar forms, now completely altered. Between crossed nicols the relic structure, seen in ordinary light and shown in the photomicrograph, vanishes, a microcrystalline aggregate of quartz and kaolinite taking its place. It will be observed that the rock exhibits no signs of deformation at all and no evidence whatever of any of the intense deep-seated metamorphism that characterizes the schist series.

Río Quijos Samples (pre-Albian?)

We questionably assign to this category two samples from the Río Quijos, Nos. 11 and 12. These rocks are of doubtful origin and uncertain relations. Specimen No. 11 was secured along the road between Quijos bridge and the cable crossing over the Quijos River, one mile from Baeza, at an elevation of 5870 feet. Specimen No. 12 came from a massive outcrop on the left bank of the Río Quijos at the cable crossing, one fifth of a mile north of No. 11 at 5852 feet elevation.

- ***Specimen No. 11*** is a limestone breccia whose origin is obscure. It is composed of finely granular crystalline carbonate, carrying patches or fragments of very coarsely crystalline carbonate that presents evidence of sever crushing; and shattered grains and areas of quartz, transected by veinlets of carbonate.

Veinlets of carbonate cut the whole rock mass as well, intersecting, ramifying and forming a carbonate-filled fracture system in a carbonate rock that is itself a breccia.

- ***Specimen No. 12*** is a serpentinized rock of doubtful origin. It is composed of lamellar antigorite with heterogeneous grouping in places, as well as in rosettes, blades, fan-shaped leaves and fine aggregates. Occasional patches resemble bastite, possibly representing completely destroyed orthorhombic pyroxene. In addition, there is a little fibrous anthophyllite (gedrite) and considerable carbonate with steel-gray interference colors that may contain iron and perhaps magnesia as well as lime. Irregular grains and groups of grains of magnetite and pyrrhotite are sparingly distributed through the rock, which contains no trace of any original structures unless the possible bastite areas connote former pyroxene crystals.

It is possible that this rock may have been derived from a basic igneous rock of the nature of a peridotite, but there is no definite proof of this in the sections.

c. The Granites

We have no information regarding the age of the granites of eastern Ecuador. We found them in three regions: one on the Río Pastaza, another in the country south of the Guacamayos mountain ridge, between it and the Río Jandache, and a third on the Río Napo a few miles below Napo, where the granite has a peculiar occurrence.

Río Pastaza

- ***Specimen 7b***. Between the sedimentary rocks of Cretaceous age at the mouth of the Río Topo and in the vicinity of Mera, from 4000 to 3800 feet above the sea, there is a mass of red granite which is several miles wide (the distance by trail across this is nearly ten miles). We have previously referred to the presence of rhyolite in the midst of this granite (samples Nos. 7a and 7c). The presence of this granitic mass between the two sedimentary areas is peculiar but we do not know what relations exist between the granite and the sediments.

The sample of granite from the Río Pastaza was collected between the hut called Cashaurcu and a ridge called Abitagua about three miles west of Mera on the north bank of the Río Pastaza. The rock is strikingly graphic in a very coarsely microscopic way, the grains ranging from one to two millimeters in dimensions. Quartz and alkali feldspar compose over 98% of the specimen. The feldspar consists chiefly of orthoclase, cryptoperthite and very little oligoclase-albite. It is all turbid from slight kaolinization, and the quartz is crowded with liquid and gas inclusions. A few little magnetite crystals and tiny zircons represent the minor accessory components, and an occasional microscopic fracture is filled with epidote. In addition to slight kaolinization many of the feldspars are very sparingly flecked with fine scaly sericite and minute random patches of zoisite-epidote, but on the whole, the rock, a typical graphic granite, is comparatively fresh. Figure 24 illustrates the general character of this specimen.

FIG. 24 – Río *Pastaza granite* – Photomicrograph, nicols crossed, showing graphic structure. Over 98% of the rock consists of quartz and feldspar in graphic intergrowth. ×22.

Río Urcusikiyacu

- ***Specimen a***. The trail from the Guacamayos Ridge south toward the Río Napo crosses an area of granite lying between the base of the ridge and the Río Jandache, where the presence of altered volcanics beneath the Albian sediments which bound the south wall of the valley of the Río Jandache has previously been referred to. The sample was collected from the trail on the right bank of the Río Urcusikiyacu, 3.33 miles north of the Río Jandache at an elevation of 4630 feet above the sea. The specimen of granite collected in this locality is a coarse textured, very inequigranular, light colored rock composed of quartz, albite, microperthite, microcline-microperthite, and a little biotite. The feldspars and the biotite show only incipient alteration, and there is a slight development of limonite in minute hair-fractures in the rock. There is some evidence that the perthitic feldspars originated through partial replacement of earlier orthoclase by end-stage albite; this is shown by the extremely ragged unoriented albite streaks in the orthoclase that cuts across the cleavages, and by the interstitial and marginal distribution of albite and quartz that have effected some marginal replacement of the earlier feldspar. The rock is a simple biotite granite.
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Río Napo

- ***Specimen b***. A very peculiar occurrence of granite was observed on the Río Napo, about five miles below the pueblo of Napo. On the left bank of the river at a place called “Remolino de Latas”, nearly horizontal limestones of Turonian age were seen. On a hill about one hundred feet above the surface of the river, we encountered several boulders some six feet in diameter, lying on the limestones. We are ignorant of both the source and the origin of the granite boulders. They have the appearance of boulders transported either by glaciers or flows of lava; they may possibly represent an inlier of granite, but this is very doubtful.

The sample is a simple biotite granite that differs from the granite on the Urcusikiyacu river only in minor internal structural details, and in the degree of alteration of the feldspars. The component grains are extremely irregular in outline, with strongly interlocking margins. The interlocking of the quartz and feldspar develops into micrographic structures in places, and there is a tendency toward the production of protoclastic structures on the margins of occasional grains. The feldspars are in large part microperthite and orthoclase, with a smaller amount of oligoclase. The orthoclase and microperthite are very turbid, owing to the formation of opaque-white kaolin mixed with a little sericite and minute grains of zoisite-epidote. Some of the biotite present has been altered in part to chlorite. Occasional random grains of magnetite and a few minute grains of zircon form the only accessories.

d. Quaternary lavas

All the metamorphic and igneous rocks described in the preceding pages refer to rocks judged to be pre-Andean in age. They were probably metamorphosed and extensively altered before the uplift of the Andes, which we now believe took place in very late Tertiary time.

The lavas which were extruded and the ash which was cast forth over the surface during the formation of the Andes, and up to the present day, is characterized by freedom from alteration. The component minerals are always perfectly fresh. Where one can examine the lava streams which are still uneroded, it is possible to recognize these lavas without petrographic study.

We have previously referred to the lavas of the volcano Sumaco which, during the opening of the orifice in the Cretaceous sediments and during the activity of the volcano, were poured forth on the surrounding Cretaceous rocks. The lavas of Sumaco have been described (*1*), but so far, unfortunately, no one has been able to collect any samples of the lavas of the volcano "El Reventador", which came into activity in 1926 on the Río Coca.

Apart from these two centers of volcanic activity in what has been considered a region separate from the Andes, it is probable that other Quaternary and recent lavas have been poured out on the surface in other localities not yet discovered. In 1921 we noted blocks of fresh lava in several places on the sediments; on the Río Misahuallí, again on the divide between the Río Anzu and Río Puyo at about 4000 feet elevation, and also on the Río Ila a few miles above the pueblo of Napo.

The samples herewith described may represent the lower parts of recent lava flows from the volcano Antisana.

- ***Sample No. 10*** was collected on the trail from Papallacta to Baeza, at a point 16.3 miles east of Papallacta and at an elevation of 6290 feet above the sea. It is a very dark gray, slightly porphyritic, vesicular rock, somewhat rusty through weathering. The groundmass is composed of tiny microlites of fresh basic plagioclase crudely oriented in a flow structure and distributed in a mesostasis of dark altered glass which is filled with multitudes of specks of iron oxide. In addition, there are granules of partially altered olivine, granules of augite and little crystals of magnetite. Scattered through the groundmass there are somewhat larger, but not phenocrystic, crystals of labradorite, olivine and augite. The rock also carries phenocrysts of clear, zoned labradorite, commonly badly corroded and filled with groundmass matter that is distributed both zonally and heterogeneously in the feldspar; and crystals of augite, some euhedral, others exhibiting corrosion, with the development of almost colorless and more brilliantly polarizing margins quite distinct from the main part of the crystals. The augite is faintly pleochroic grayish-green to faint rose-pink, optically positive, $Z \wedge c = 38°\text{-}10°$, and has distinct dispersion. The rock is a basalt unaffected by dynamic movements and but very slightly affected by weathering. It is certainly much younger than the schist, and perhaps younger than the silicified and kaolinized andesite No. 2-b that occurs in the vicinity of Papallacta. This, however, is purely conjectural. It is probably lava from one of the neighboring volcanoes.

- ***Specimen 2*** represents an occurrence near Chalmayaca, 9000 feet south of the end of the Baeza Road. It is very dark gray, fine textured and porphyritic, with "chalky" looking phenocrysts.

The groundmass is hyalocrystalline, filled with many tiny microlites of plagioclase arranged in flowage structure, and containing irregular patches of a clear, low index substance that consists of tridymite, occurring in characteristic "spearhead" or "wedge" twins. The phenocrysts are crystal clear plagioclase and wholly altered hornblende and biotite. The plagioclase is poorly twinned but very strongly zoned; the zoning is so prominent and the change in composition so continuous that the plagioclase phenocrysts do not completely extinguish in any position.

Judging from their indices of refraction, considerably higher than balsam, and approximate extinctions (complete extinction is not found) measured from cleavages, the feldspar phenocrysts have an average composition corresponding to a basic andesine. They are veined with an isotropic substance whose index of refraction is considerably lower than 1.535, resembling analcite (?), clear and colorless in transmitted light, but somewhat opalescent by reflected light.

The phenocrysts of hornblende and biotite have been completely converted into fine mixed aggregates of magnetite and hematite. A little magnetite in euhedral grains, a few small crystals of fresh augite, and occasional turbid crystals of apatite, constitute the accessory minerals.

The rock has not been subjected to any deforming stresses at all; it is a simple andesite with a simple history, much younger than the schists, and possibly related in time and origin to the basalt No. 10.

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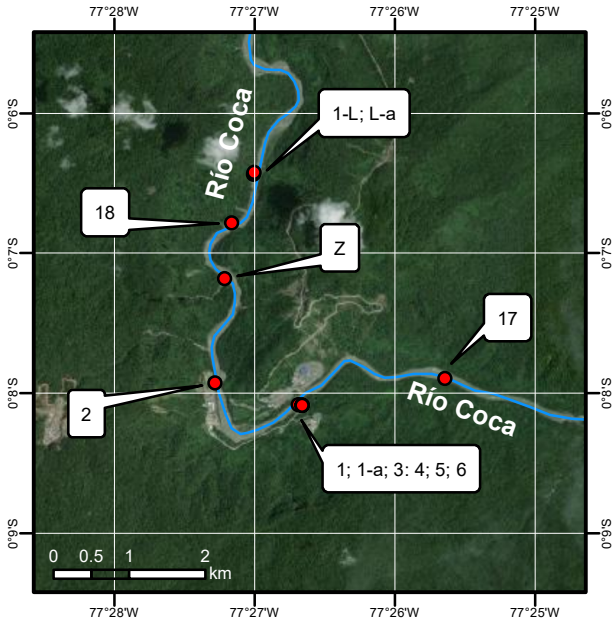
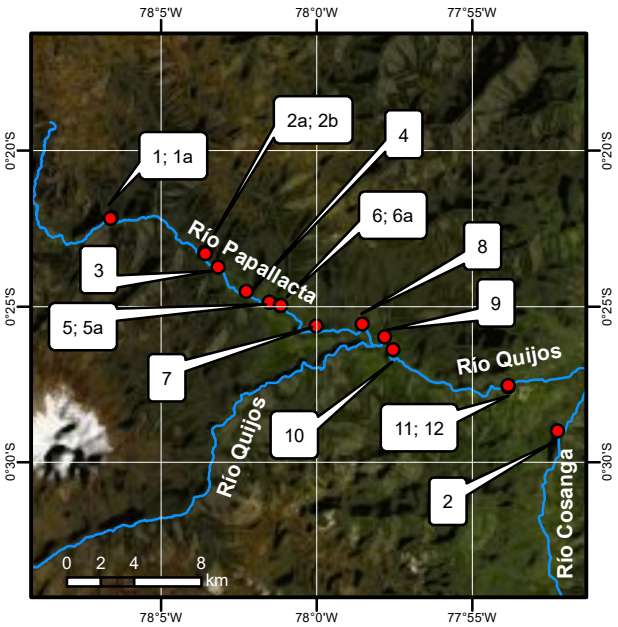
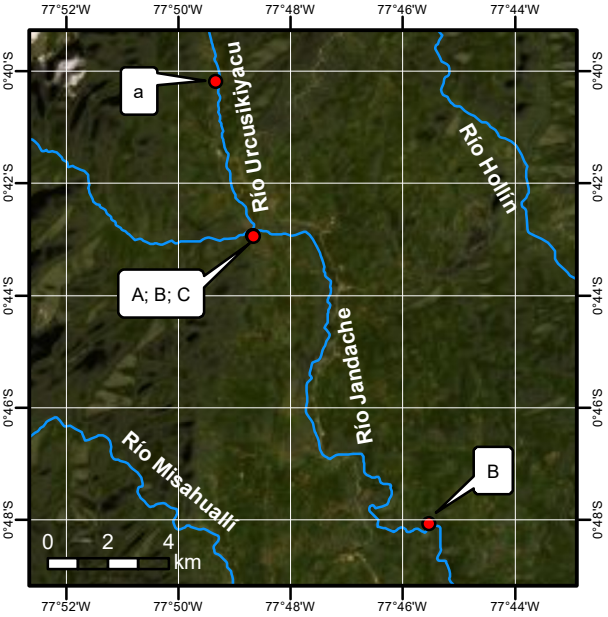
Samples' possible location



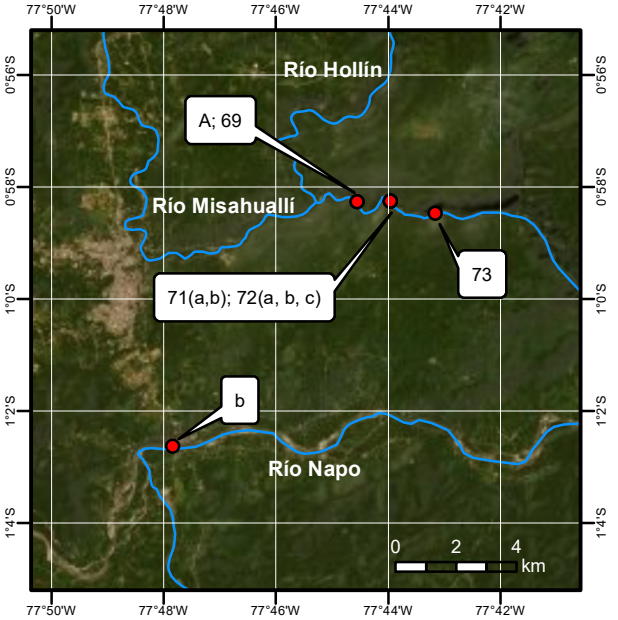
Section 1. Río Coca



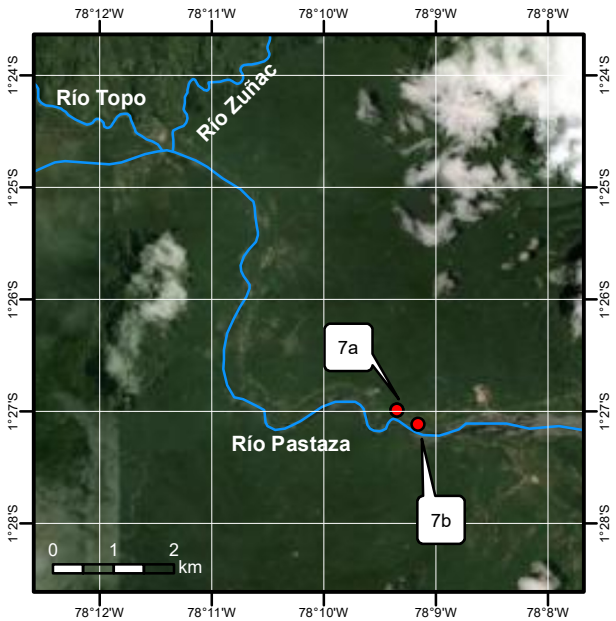
Section 2. Río Papallacta, Río Cosanga, Río Quijos



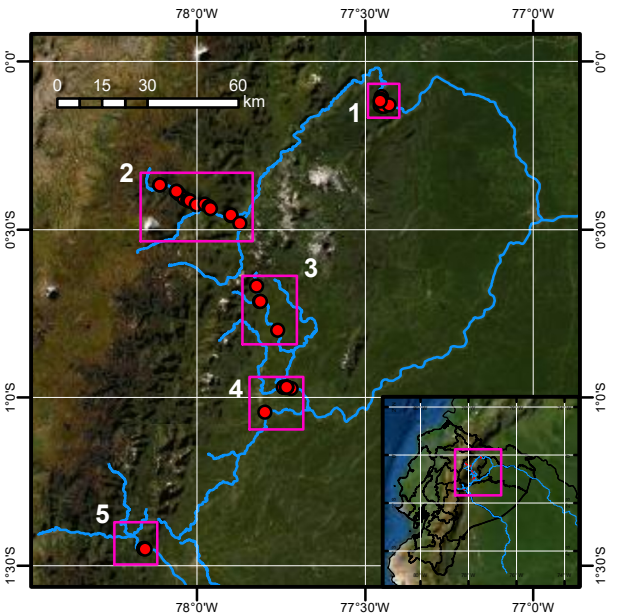
Section 3. Río Urcusikiyacu, Río Jandache, Guacamayos Mt.



Section 4. Río Misahuallí, Río Napo



Section 5. Río Pastaza, Río Topo, Río Zuñac



Sections' location